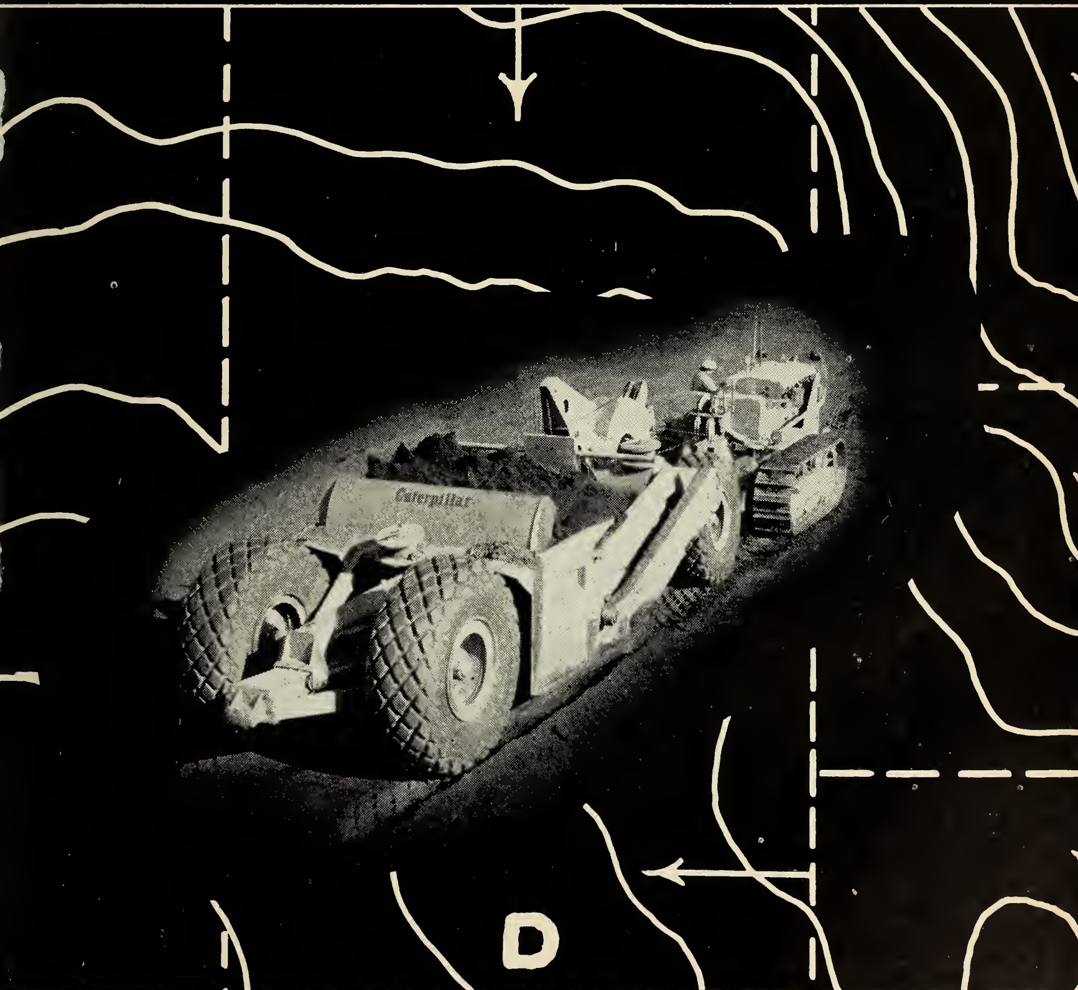
Division of Agricultural Sciences
UNIVERSITY OF CALIFORNIA

GRADING LAND FOR SURFACE IRRIGATION

JAMES C. MARR



CALIFORNIA AGRICULTURAL
Experiment Station
Extension Service

CIRCULAR 438

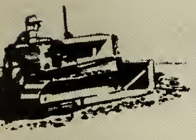
IF YOU ARE A LANDOWNER...

considering land grading for surface irrigation, this circular tells you how to go about it. It helps you decide how much of the job you want to do yourself, and how much you want done by professionals. It gives you facts that will make you a better-informed partner in your contracts with the engineers and the land-levelers. It tells you about the various pieces of equipment and what they can be expected to accomplish. And it aids you in writing contracts that will meet your needs and protect you from misunderstanding, injustice, and loss.

IF YOU ARE A CIVIL ENGINEER...

you may be interested in the land-grading and other pertinent calculations in the appendix, and in the information about contracts on pages 28 and 29.

IF YOU ARE AN EARTH-MOVING CONTRACTOR...



you find information about land-grading equipment on pages 20 to 27, about efficiency computations in the appendix, and about contracts on pages 29 to 31.

GRADING LAND FOR

JAMES C. MARR

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SURFACE IRRIGATION

Factors to Consider Before Grading

Surface irrigation requires land over which water can flow evenly and without causing erosion.

Before you take steps to grade your land for that type of irrigation you have to find answers to these two questions:

1. Is your site suitable for surface irrigation?
2. Which method of surface irrigation should you use?

Is Your Site Suitable?

There are seven general groups of conditions which may make surface irrigation unfeasible or uneconomical.

Excessively permeable soils. Sandy or gravelly soils, and soils consisting largely of organic material, are characterized by a high water intake rate. Soils usually absorb water relatively fast at first, and finally at a slower, steady rate. If the final water intake rate exceeds three inches per hour, or less in some cases, it may be assumed that surface irrigation will prove wasteful of water and may cause drainage and salinity problems in most locations due to the excessive use of water required to irrigate. Hence, unless it has been found economical to do so in a particular case, it may be a mistake to grade such land.

Insufficient soil depth. A shallow soil may be arable and irrigable and still not have sufficient depth to permit necessary grading for surface irrigation. This is particularly the case when the depth of cut required for land grading exceeds the depth of top soil with the result that cobblestones or other undesirable material are brought to the surface where they permanently reduce crop production.

Rough topography. Roughness of topography governs to a large extent the cost of grading. In this sense it is often the limiting factor in the preparation of land for irrigation. Jobs that require moving more than 800 to 1,000 cubic yards of earth per acre are ordinarily considered too expensive to undertake.

Steep slopes. Slope limitations are necessary for proper control of the irrigation water. On steep slopes, generally, water directed down the slope tends to channel and cause serious erosion. Furthermore, as the slope increases, it becomes in some cases more difficult to wet the soil without allowing an excessive amount of waste-water runoff. This is especially the case when either the border or furrow method of irrigation is used, and the length of run—the distance the water travels—is short. Specific slope limitations for the different surface methods of irrigation are listed in the table on pages 6 and 7.

Absence of drainage. A difficult-to-solve drainage problem sometimes precludes the use of surface irrigation and the need to grade land. An example of this condition are areas consisting of very flat land with porous soil and a

Guide for selecting a method of

Irrigation Method	Topography	Crops	Remarks
Ordinary furrows	Flat land slopes capable of being graded to 0.15% slope or less	Commercial vegetable crops	This adaptation of the furrow method is especially desirable for truck farming. The land surface should be graded as accurately as possible, so the ridges between adjacent furrows will be wetted through without being overtopped by the irrigation water. This is especially important if vegetable crops are planted in dry soil and irrigated up.
	Land slopes capable of being graded to 1% slope or less but preferably less than 0.4%	Row crops and fruit	Surface grading similar to that required for commercial vegetable crops, but less accurate especially for slopes greater than 0.4%.
Zigzag furrows	Land slopes capable of being graded to 1% slope or less	Fruit	This method is designed partially to check the flow of water on steep slopes. It is desirable but not essential that the grade in the direction of irrigation be uniform. Any adverse grade and sharp grade change should at least be leveled out.
Check back and cross furrows	Land slopes capable of being graded to 0.2% slope or less	Fruit	This method is especially designed to obtain adequate distribution and penetration of moisture in soils with low water intake rates.
Corrugations	Land slopes capable of being graded to slopes between 0.5% and 12%	Alfalfa, pasture and grain	This method is especially adapted to steep land and small irrigation streams. An even grade in the direction of irrigation is desirable but not essential. Sharp grade changes and reverse grades should at least be smoothed out. Due to the tendency of corrugations to clog and overflow and cause serious erosion, cross slope should be avoided as much as possible.
Graded contour furrows	Variable land slopes of 2% to 25% but preferably less than 8%	Row crops and fruit	Especially adapted to row crops on steep land, though hazardous due to possible erosion from heavy rainfall. Unsuitable for rodent-infested fields or soils that crack excessively. Actual grade in the direction of irrigation 0.5% to 1.5%. No grading required beyond filling gullies and removal of abrupt ridges.

surface irrigation to fit your land

Irrigation Method	Topography	Crops	Remarks
Widely spaced borders	Land slopes capable of being graded to less than 1% slope and preferably 0.2%	Alfalfa and other deep-rooted, close-growing crops and orchards	The most desirable surface method for irrigating close-growing crops where topographical conditions are favorable. Even grade in the direction of irrigation is required on flat land and is desirable but not essential on slopes of more than 0.5%. Grade changes should be slight and reverse grades must be avoided. Cross slope is permissible when confined to differences in elevation between border strips of 0.2 to 0.3 foot.
Closely spaced borders	Land slopes capable of being graded to 4% slope or less and preferably less than 1%	Pastures	Especially adapted to shallow soils underlain by clay pan or soils that have a low water intake rate. Even grade in the direction of irrigation is desirable but not essential. Sharp grade changes and reverse grades should be smoothed out. Cross slope is permissible when confined to difference in elevation between borders of 0.2 to 0.3 foot. Since the border strips may have less width, a greater total cross slope is permissible than for border-irrigated alfalfa.
Rectangular checks	Land slopes capable of being graded so single or multiple tree basins will be level within 0.2 foot	Orchards	Especially adapted to soils that have either a relatively high or low water intake rate. May require considerable grading.
Contour checks	Slightly irregular land slopes of less than 1%	Fruit, rice, grain, and forage crops	Reduces the need to grade land. Frequently employed to avoid altogether the necessity of grading. Adapted best to soils that have either a high or low water intake rate.
Contour ditches	Irregular slopes up to 12%	Hay, pasture, and grain	Especially adapted to foothill conditions. Requires little or no surface grading.
Portable pipes	Irregular land surface	Hay, pasture on small scale	Minimum preparation of the land surface required.

fairly high water table lying within closed basins or floodways. In order to grow most crops successfully under these conditions, it is necessary to apply irrigation water accurately in sufficiently small depths to avoid raising the water table to the surface. This is sometimes impossible with surface irrigation and thus the grading of such land may not be advisable.

Unstable soil surface. Under some soil or soil profile conditions "sink holes" develop in flood-irrigated fields to such an extent that land and water losses become prohibitive. The trouble arises from irrigation water running into gopher holes, cracks or crevices followed by caving of the surrounding ground surface and the loss of very large volumes of soil and water into the subsurface. The ideal remedy for such situations is, of course, the use of pipe lines instead of ditches, and overhead instead of surface irrigation. Under these conditions, grading the ground surface would be uncalled for.

Small irrigation streams. When a small stream of water is used to surface-irrigate a fairly porous soil, great inefficiency may occur due to unequal wetting of the upper and lower ends of furrows or checks. Better use of the water in such cases might be possible by adopting overhead irrigation.

Which Method of Irrigation?

There are at least 11 different forms of surface irrigation which have a bearing on land grading. The table on pages 6 and 7 lists the most important of these methods and the conditions for which the various methods of surface irrigation are suitable.

Steps to Take to Prepare for Land Grading

After you have decided that your site is feasible and economical for surface irrigation, and you have chosen the method of irrigation you will use, the time has come to prepare the land for grading. At this point you have three choices.

1. You can ask a civil engineer to handle the surveying and land-grading calculations, and an earth-moving contractor to take care of the grading.

2. You can find a contracting firm which will handle the engineering as well as the grading.

3. You can undertake all or part of the work yourself.

There are good reasons for preferring the first arrangement. The extent of the surveying, the involved nature of the land-grading calculations, the high cost of earth-moving equipment, and the skill required for its efficient operation may make it very difficult—perhaps inadvisable for landowners without prior experience—to undertake the job alone.

If you arrange with a single contractor to handle the engineering as well as the grading, you may place him in a position to favor himself by planning a larger job than necessary and by failing to rigidly check and finish his land grading work to the proper degree of tolerance.

If you hire engineers and contractors to do the work, you should make sure that the work is placed in capable hands, and that the plan to be followed is suitable and equitable. In general, you stand the best chance of getting a good job done by thoroughly posting yourself on the requirements, and then letting separate contracts for the engineering and the earth moving. This circular, in the following sections, helps you gain information about the job to be done and offers suggestions concerning the contents of the contracts.

Selecting the time

It is uneconomical and injurious to the soil to operate earth-moving equipment

during wet weather or on muddy ground. In all parts of the State you can depend upon sufficient dry weather during the six months' period from May through October. This should be enough to complete any ordinary land-grading job provided the operation is not delayed too long and sufficient equipment is used. Frequently delays are occasioned by use of the land for growing crops and by the men and equipment being engaged in other work. Depending upon the depth of earth to be moved, the length of haul, and the type of equipment used, an experienced operator with one grader of average size will grade land at the rate of one to eight acres per day. If there is more land than can be graded within the expected period of fair weather, either additional units should be put to work or some of the area should be left to be graded at another time.

Land clearing

Removal of the native vegetation is sometimes left to be taken care of by the earth-moving contractor. It may consist of roto-beating or railing, windrowing, and burning of small desert brush, or it may include the removal with heavy equipment of trees and large brush. Bulky crop residue should be burned or otherwise reduced or disposed of. In any case, the clearing of the land must be completed before earth moving starts. (Land clearing methods are described in U.S.D.A. Farmers' Bul. 1526.)

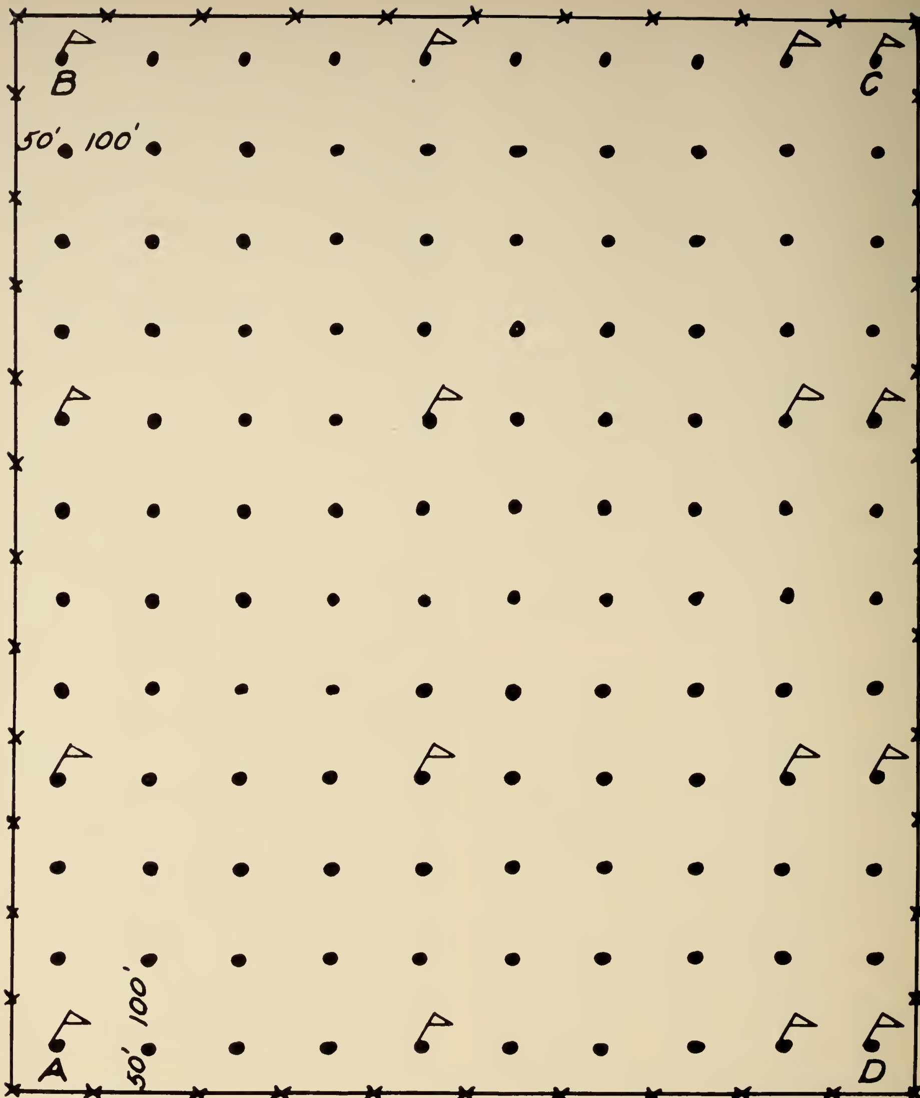
Surveying

When the time is right and the land is available and cleared, work is usually started by mapping the topography. However, in some cases this operation can be dispensed with and in others it may be impractical unless some preliminary grading is done. It need not be done if the land slopes are relatively steep, 1% or more, and experienced equipment operators are available who can grade such steep land satisfactorily by eye. The preliminary grading is necessary for hummocky land which otherwise would require an excessive amount of surveying for topographic mapping.

Staking

In order to provide marked spots where the relative elevations of the original ground surface may be obtained and at which may be indicated the depths of cut and fill for obtaining a graded surface, stakes are set according to a pattern similar to the one indicated in the chart on page 10. If two adjacent sides of a field are straight lines which form a 90-degree angle as in the case illustrated, the staking problem is relatively simple. For crooked-sided fields there is the added problem of establishing the two straight lines and making them conform as nearly as possible to the boundaries of the area. The two adjacent sides of either the blocked-out area or the straight-sided field are required to serve as guide lines for the staking. The stakes are set at equal distances (100 feet is the usual station distance) along lines similarly spaced and parallel to the two guide lines. The grid pattern thus formed consists of squares, though it may be made up of any type of equilateral parallelogram that fits a field. If the pattern is other than square, it is necessary for computing purposes to measure and note the angle between the two guide lines.

The details involved in staking a field with the two adjacent straight sides are as follows: Lath, approximately 3/8″ by 1¾″ by 4′ are used as stakes. They should be sharpened and driven into the ground far enough to insure that they will withstand strong wind. According to the chart on page 10 the first stake is flagged and permanently set at A, 50 feet, or one-half the station distance inside the field from either guide line. Flagged stakes are also set temporarily at B and D. Starting at A and lining in on B, the distance between A and B is measured and permanently staked at 100-



The pattern used for staking a field which is to be graded.

foot intervals with the stakes flagged every 400 feet. The stake at B is reset at the last 100-foot station on the line. The distance from A to D is similarly measured, permanently staked, and flagged. The line DC (or—if more convenient—line BC) is then measured off equal in length and approximately parallel to line AB and temporarily staked and flagged to correspond with lines AB and AD. The line between B and C and those from the stations marking the 400-foot intervals along line AB to the corresponding points on the opposite side of the field are then measured, staked, and flagged to correspond to the staking of line AB. At the same time the flagged stakes which were temporarily set at C and at the 400-

foot intervals along DC are reset at the last 100-foot station on these lines. The lines from the 400-foot intervals along AD to the corresponding points on the opposite side of the field along line BC are similarly measured, staked, and flagged. A sufficient number of stakes are then in position to sight in the rest by eye. Essentially the same procedure is followed for staking an irregularly shaped field. In this case the lines of stakes are extended to cover any area more than 100 feet wide lying outside of the blocked out parallelogram. The position of any stake can be located quickly in the field or on a map if the lines of stakes are numbered in one direction and lettered in the other, and each stake is numbered and lettered accordingly.

Where the topography is unusually irregular and no preliminary leveling is done, more frequent grade stakes may be called for than are provided by the 100-foot spacing. Stakes may be set at 50-foot intervals without seriously obstructing the movement of equipment in the field. However, halving the usual station distance adds greatly to the work of staking a field. On a 40-acre tract of land measuring 1,320 feet to a side, 169 stakes are required to mark points 100 feet apart, while 625 are needed if the interval is reduced to 50 feet.

As landowner you may, by working with or under the direction of an engineer, perform at least part of the work of staking your field.

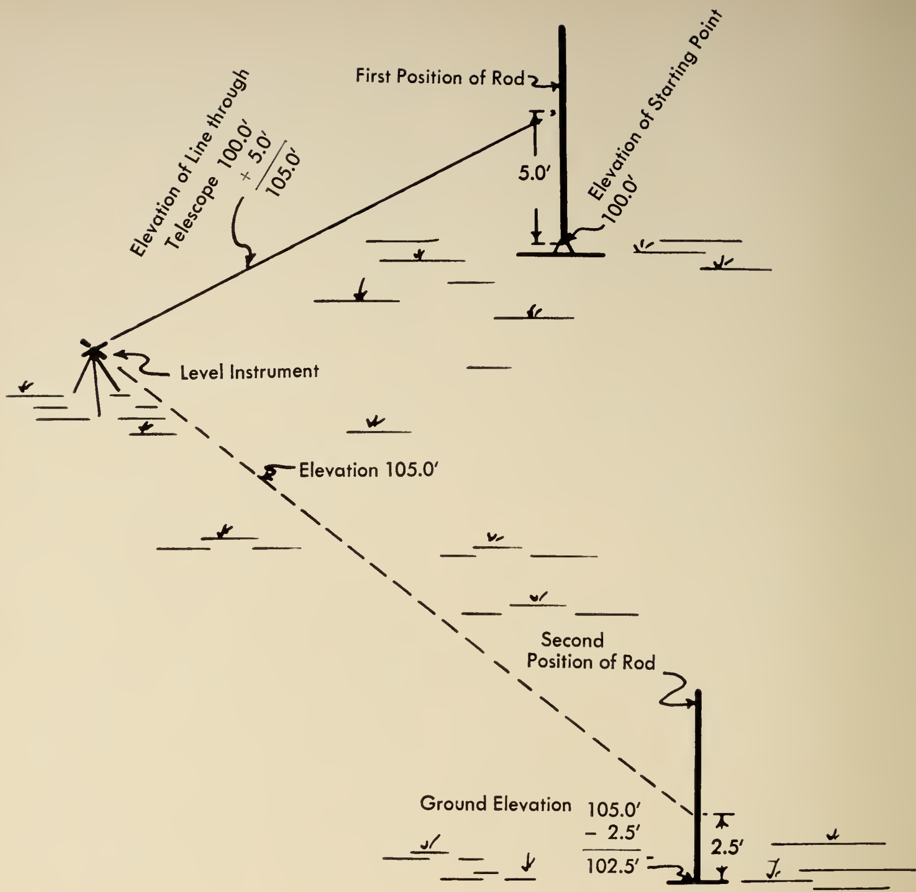
Mapping the Topography

If you have had no training or experience in surveying, you may find the discussion on mapping the topography difficult. You also should realize that, unless the mapping is put into competent hands, the investment of possibly $60 to $100 per acre for land grading is jeopardized.

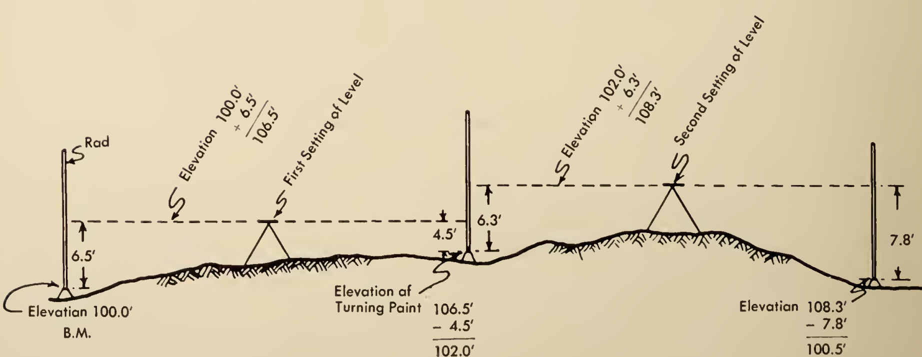
There are several surveying procedures for mapping topography, but where land grading is the aim, the usual practice consists of using an engineer's level for determining the relative ground surface elevations and spotting these elevations directly on a base map.

Rod reading. The ground surface elevations are obtained with an engineer's level as illustrated in the diagrams on page 12. When the instrument is properly leveled, all points which fall in the same plane with the horizontal cross hair are of the same elevation. A leveling rod is used to measure the vertical distance from the ground at each stake to the level of the horizontal cross hair in the instrument. This measurement is called a rod reading. Differences in rod readings denote changes in elevation. Some engineers simply record the rod readings first at a permanent reference point called a bench mark or B. M. and thence at each grid corner, keeping in mind that elevation increases as rod readings decrease and vice versa. Other engineers start the survey as illustrated on page 12 by obtaining a rod reading on a B. M. of known or assumed elevation, add the rod reading to that elevation to obtain the elevation of the cross hair in the instrument and thereafter subtract the rod readings from the cross hair elevation to obtain ground surface elevation at each stake. In this case elevations as well as the rod readings are recorded at the corresponding points on the base map.

Resettings of level. One setting of an engineer's level is sufficient to obtain a rod reading at each of the 169 stakes in a 40-acre tract provided (1) the variation in elevation does not exceed the length of the rod; (2) the view is unobstructed; and (3) the stability of the instrument is not affected by wind. Otherwise, for larger fields, or when a small farm level is used, it is necessary to reset the instrument and arrange to make the rod readings or elevations comparable with those obtained before the instrument was moved. To accomplish this a rod reading is obtained on a point, before moving the instrument, from which



Starting a topographic survey from a bench mark.



Moving instrument while making a topographic survey

a second rod reading can be made when the instrument is reset. This point is called a turning point and should be of a semi-permanent nature—a nail driven into a fence post or a 2″ × 2″ × 12″ stake driven flush with the ground surface and plainly marked with a guard stake or stakes so it can be found. If a square 160-acre tract is being surveyed and one setting of the instrument for each 40 acres is sufficient, a single turning point in the middle of the tract may suffice. If the engineer is recording rod readings only, he arranges either to reset the instrument at the same elevation as before or at a level which differs from its original height by a simple figure such as one foot which readily can be added or subtracted as required to make the rod readings taken from the new instrument setting comparable with those obtained before moving the instrument from its first position. If the engineer is recording elevations, he must before moving the instrument determine in the manner already described the elevation of the turning point. Upon resetting the instrument he starts with the rod reading on the turning point and thereafter follows the same procedure as before. This performance is illustrated diagrammatically on page 12 (bottom). Accuracies of ground surface rod readings to the nearest 0.05 foot and readings on turning points to the nearest 0.01 foot are required especially when the land slope is 0.2% or less.

In case the grid stakes are 100 feet apart and the surface elevations at this interval fail to show the surface relief in sufficient detail for accurate determination of the best land grade, the distance between points where rod readings are obtained may be reduced to 50 feet or less by taking additional rod readings between stakes. In many cases this is a satisfactory substitute for a closer spacing of grid stakes.

Rod readings on freshly cultivated land should be made to conform to the natural ground surface. Frequently a tractor is driven along each line of stakes to compress the soil for this purpose and the rod readings are taken in the wheel tract next to the stakes. Another practice consists of tamping the ground at each stake with the rod before the reading is made. As an alternative to such practices, all rod readings may be increased by the estimated amount the ground surface must finally sink to give the soil its original weight per unit volume.

Selecting the spot for rod reading. Judgment and care should be exercised in selecting a representative spot for a rod reading. Staking calls for an accurate spacing and alignment of stakes with no allowance for avoiding small surface irregularities. Thus the rod readings are not always taken exactly at the stakes, and it may not be always assumed that the amount of cut or fill required for grading can be measured from the ground at the base of the stakes. As will be described on pages 18 and 19 under methods of posting, a reference line or level is marked on each grid stake to serve that purpose.

Base map. The base map upon which the level notes are recorded, consists of a sheet of cross-section paper laid off in inch squares mounted on a plywood board of convenient size for carrying. The squares printed on this paper represent the staking pattern, the sides of the squares being the interval between stakes, and the corners, the locations of the stakes. Delineation on the cross-section paper of the boundaries of the area with respect to the staked interior completes the base map.

All survey information is recorded on this map. With one exception the rod reading is always placed in a horizontal position above and to the right of the point on the map representing the grid point where the reading was made. The one exception is a reading at a turning point. In this case the reading is placed in a diagonal position in the middle of

the grid square nearest the turning point and in line with the location of the instrument. Turning points may be further identified by inscribing them in a small triangle. If elevations are used, they are placed in line with and to the left of the corresponding rod readings. After the land grading calculations, which are described later, have been completed, the grade and cut or fill figures are transcribed on this map in positions beneath the corresponding elevation and rod reading. Convenient forms of entry when rod readings only are recorded and when both rod readings and elevations are noted are shown on page 15.

Contour lines. To make this survey information more readily understood and studied, lines are drawn connecting points of equal elevation. These lines are called contours. From them it may be seen at a glance where hills and hollows occur and how much and in which direction the ground slopes. It is desirable to have this picture so that a property may be divided into fields that can be graded and irrigated individually to the best advantage. A few simple rules govern the drawing and interpretation of contour lines.

1. Contour lines are located by an interpolation procedure based on the assumption that the slope of the land surface is uniform between adjacent grid corners. See example below.

2. The difference in elevation between successive contours is called contour interval. The following intervals are recommended for different slopes.

Recommended Contour Interval

Slope in feet per 100 feet	*Contour interval in feet*
0– 1	0.2–0.5
1– 2	0.5–1.0
2– 5	1.0–2.0
5–10	2.0–5.0

3. The slope along a contour line is zero. Thus, a contour line connects only points of equal elevation.

4. On plane surfaces contours are straight lines parallel to each other.

5. The area within a contour line which closes upon itself is either a summit or a depression.

6. When completely enclosed within another contour line, a contour must also close upon itself. It never consists of a single line.

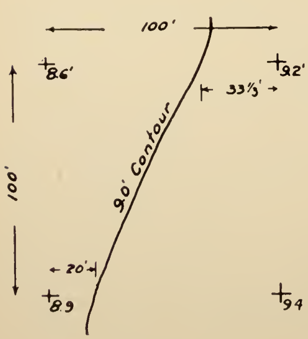
7. Except in such rare cases as overhanging cliffs and caves, contour lines cannot merge or cross one another.

8. The direction of steepest slope is always perpendicular to the contour lines.

9. Closely spaced contours denote steep slopes; widely spaced contours, flat slopes.

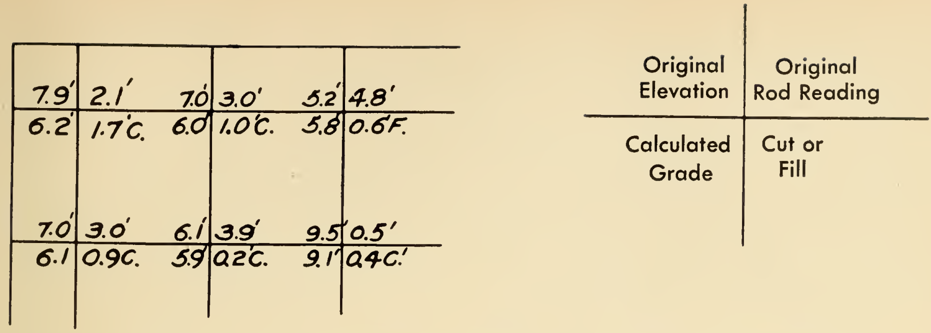
Selection of Areas for Separate Grading

A step of greatest importance, in some cases, is the division of an area according to its contours into parcels of land

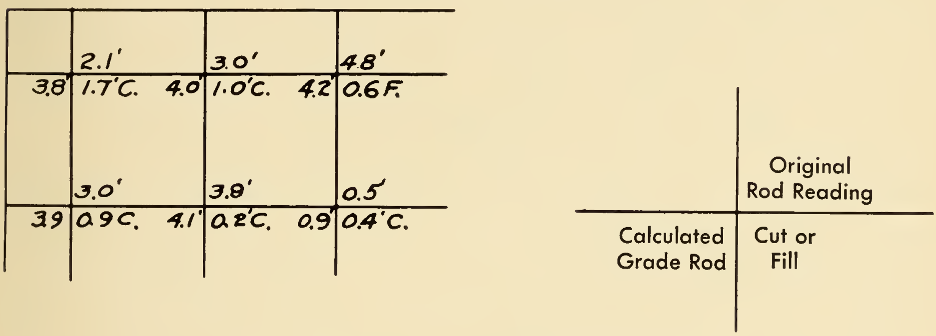


Difference in elevation = 9.2′ – 8.6′ = 0.6′; from 9.2′ – 9.0′ = 0.2′; therefore the point on the 9.0′ contour line is $\frac{0.2}{0.6}$ = ⅓ of the total distance from the 9.2′ to 8.6′ grid corners.

Difference in elevation 9.4′ – 8.9′ = 0.5′; 9.0′ – 8.9′ = 0.1′; therefore the point on the 9.0′ contour line is ⅕ of total distance from the 8.9′ to 9.4′ grid corners.



Convenient forms of recording survey data on base map when elevations are used (top) and when rod readings only are used (bottom).



that can be graded separately to the best advantage and at a minimum cost. Here are examples of different contour patterns which may warrant separate handling and which are illustrated in the diagram on page 16.

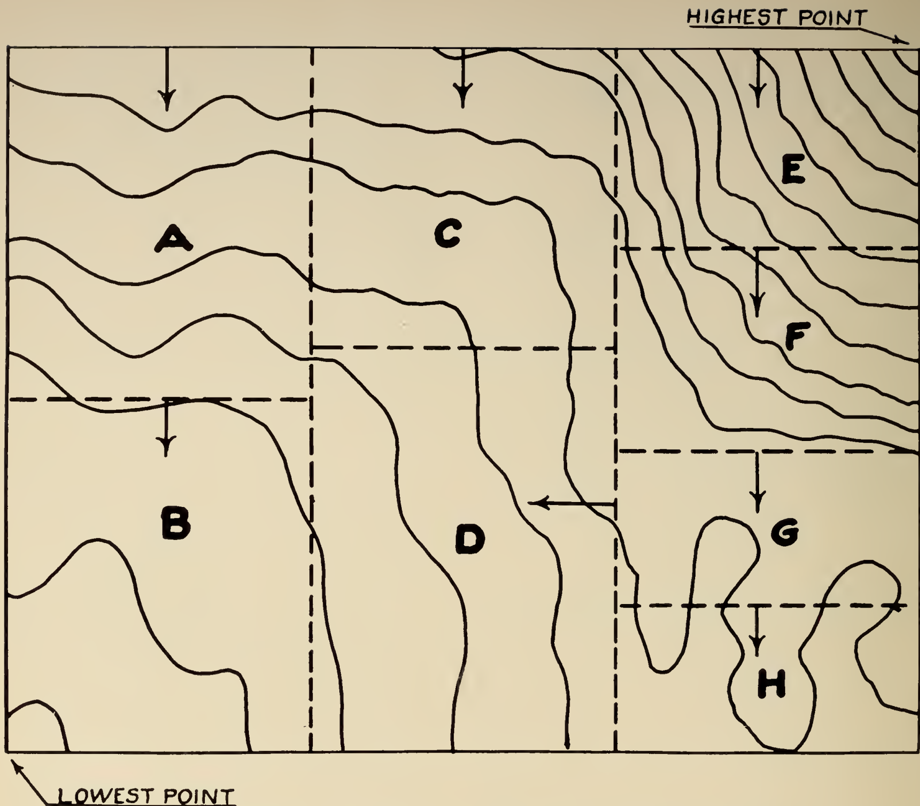
1. Abrupt major difference in contour interval implies a sharp change in slope. Separation may be desirable along the line of slope change as in the case of field A and B.

2. Sharp bends in otherwise nearly straight contours indicate an important change in the direction of maximum slope. While such an area might be irrigated as a whole by contour checks, graded contour furrows, or contour ditches, separation into fields at the bend is desirable if either border or furrow irrigation is planned as in the case of fields C and D.

3. Contour lines either close together or far apart may imply that the average natural slope is either too steep or too flat to be satisfactory for the land use intended and that it must be graded to a lesser or greater slope. In such cases the least permissible amount of grading will be required if the length of field in the direction of irrigation is the minimum that can be watered satisfactorily. Such separation into fields is shown in fields E, F, G, and H.

4. Great irregularity in spacing and direction of contours may show that the topography is nonuniform to the extent that it fails to show where a separation into fields can be made advantageously. Such areas may be set apart to be graded individually as units.

5. Excessively irregular and/or closely spaced contours indicating land that can be leveled only at great expense and for that reason may be partitioned off as unsatisfactory for irrigation by surface methods.



Division of an area into fields in accordance with different topography.

While dividing a property in accordance with its original contour patterns, an endeavor should be made to keep individual fields rectangular in shape. Irregularly shaped fields are difficult to irrigate and cultivate and should be avoided if possible. Also, provision should be made at this time for surface drainage.

Planning the Irrigation Distribution System

It is necessary that the design and the map location of the irrigation ditches or pipe lines and the surface drainage ways be adjusted to fit the lay of the land. A full explanation of how this is done is given in California Agricultural Experiment Station Circular 362. In addition, if the land has little slope or it is desirable to maintain without the use of structures a high water level in the ditches with respect to the land, special provision is made for extra soil for ditch construction. A "ditch pad" or "ribbon fill" of the proper width and depth serves this purpose. The volume of this fill should be sufficient to form the ditch banks. Usually a fill 10 to 15 feet wide and 1 to 1½ feet high is sufficient. Ditch pads are located and marked for depth of fill with stakes set at either edge of the proposed fill at 100-foot intervals.

Land-Grading Calculations

The level to which the surface at each grid stake is raised or lowered is termed grade. Many different methods of com-

puting grades are used. By using any one of these methods you can delineate a new land surface that will irrigate perfectly, but you cannot always be sure that the cost will be the minimum. To consider both the cost and suitability for irrigation, the rules for land grading calculations that seem best to follow are:

1. Consider first grading the area to a single plane which is so located as to require moving the minimum amount of earth.

2. In case the plane which requires the least amount of earth moving is unsuitable due to its slope, or the elevation at which water must be delivered, adapt a plane as close to it as possible.

3. If grading to a single plane is too costly, adhere closer to the natural topography than is possible with a single plane, while staying within the allowable limits of degree and variation of slope, as outlined on pages 6 and 7.

Three methods of grade calculations are discussed here

1. Least-squares and average profiles
2. Cross-section
3. Two-way profile

A detailed discussion of the three methods is found in the appendix on pages 32 to 40.

Cut vs. Fill Requirement

The depth of soil that must be removed or added to make the original ground surface conform to a prescribed grade is referred to as cut or fill. For example, if the original surface elevation is 10 feet and the land grading plan calls for 8.5 feet at that point, a cut of 1.5 feet is required. If these figures are interchanged so that the elevations before and after grading are 8.5 and 10 feet respectively, a fill of 1.5 feet instead of a cut of like amount is indicated. The volume of cut is the area of cut multiplied by the average depth of cut. Likewise, the volume of fill is the product of area and depth of fill.

Volumes of cut and fill. It is the experience in grading land with modern earth-moving equipment that a greater volume of cut than fill must be allowed in order to provide a sufficient volume of cut to take care of the called-for volume of fill. This finding applies to all soils and conditions of soil and thus may not necessarily include the subsidence of freshly cultivated or naturally loose soil previously mentioned as most accurately appraised and allowed for while obtaining the rod readings. A common opinion often expressed is that fills made with heavy equipment are compacted to the extent that the extra volume of cut is required to complete them. It would appear more logical to expect compaction of the soil that remains in the areas of cut, since they suffer the most traffic by the earth-moving equipment and besides are exposed to the greater compacting forces owing to the extra power used while loading. It is possible that such unequal compaction is a factor to be considered in case the necessity arises to grade wet land. No evidence has been found by the author of such an effect on dry mineral soils. Perhaps the most likely and more important explanations are that a tendency exists to crown slightly the ground surface between grade stakes and that loading and transportation losses occur. For the same reason that a pillar of the same diameter throughout its length erroneously appears smaller in the middle than at either the top or bottom, level ground surfaces between grade stakes appear to dip in the middle. To the extent that operators of the grading equipment allow this optical illusion to influence their judgment, crowning between grade stakes will occur. The importance of this factor is shown by the results obtained from checking the levels on several newly graded fields in the vicinity of Davis. Seventy-five to 90 per cent of the midpoints between grade stakes were found to be 0.05 foot or more above grade, while the remaining middles

were approximately at grade. It is to be expected that deviations from the prescribed grade in excess of 0.1 foot except when confined to small spots will be discovered and corrected, but lesser discrepancies are usually allowed.

Bases for estimates. It is rarely possible to estimate exactly the volume of cut that will be required. Consequently it should be recognized by all concerned that the original posting of grades in the field is somewhat tentative and subject to change after the work of grading the land is under way. The following observed performances suggest bases for making the estimate.

When the depths of cut are uniformly only a few tenths of a foot, it is found necessary to allow up to 100 per cent more cut than fill. This large allowance of cut is undoubtedly due to the relatively large proportion that any occurrence of compaction, crowning, or waste of soil bears to the volume of cut. For example, if cuts range below 0.4 foot, from 70 to 100 per cent cut overage very likely must be used.

In case the soil is composed principally of organic material such as peat or muck, it is the experience that at least twice as much cut as fill must be provided. Here the major factor without question is compaction.

Under some conditions the type and size of earth-moving equipment to be used must be considered. Wheel tractors generally, because of their operating speed are likely to cause uneven distribution of the soil.

Notably some earth-moving contractors require more cut to complete a job than do others. This is due, without doubt, to different tendencies upon the part of the operators of the graders to crown between grade stakes.

For the average job involving clay loam soils with low moisture content, and from 300 to 500 cubic yards per acre excavation, from 20 to 45 per cent more cut than fill is usually needed, while in extreme cases of heavy or light textured soils and deep or shallow excavation the percentage can be as little as 5 per cent and as much as 100 per cent.

Computations of cut and fill adjustments can be found in the appendix on pages 40 and 41.

Posting Cuts and Fills in the Field

Responsibility. If the earth-moving contractor is expected to bear the full responsibility of performing his work economically, he should be supplied a copy of the completed base map and the cuts and fills should be posted for him in the field at all of the grid corners in a manner that is easy to understand. He needs the base map to study and to refer to from time to time in order to plan the earth moving efficiently and to check on the excavation being required. The posted cuts and fills are essential for showing the operators of the earth-moving machines where and how much to grade.

In case direction of the earth moving is the responsibility of the landowner or his engineer, it is not necessary and may not be desirable to reveal the whole leveling plan to the earth-moving contractors and his workmen. Instead, the work may be laid out in the field piecemeal by posting cuts and fills as they are needed to keep the graders supplied with work. This procedure requires the constant attention of the individual who directs the earth moving, but it gives close control over earth-moving operations and saves reposting of cuts and fills in case it becomes apparent that too little or too much cut has been allowed in estimating the requirement.

Methods for posting. A number of methods for posting cuts and fills in the field are used. The important requirements are:

1. Establishment by means of a mark placed on each grid corner stake, or by other reference at each grid corner, of an elevation which corresponds to or has a known height with relation to the point

where the rod was placed for obtaining the original elevation. This reference serves as a level from which the depth of cut or fill called for at the point can be measured quickly and accurately.

2. The depth of cut or fill must be posted at each grid corner in a manner that will be clearly visible to operators of grading equipment for several hundred feet.

3. The markings should be sufficiently durable to serve until grading is completed.

Reference. One of the practices followed requires that a mark to serve as a reference be placed at the height on each grid stake which is one foot higher than the point where the rod was placed to obtain the original ground-surface elevation. It is usually possible to place this mark while obtaining the original ground elevation by noting the point on the stake that corresponds to the one-foot mark on the level rod. In case the rod is too far from the stake to make this possible within the desired degree of accuracy, a second rod reading is procured at the stake and the stake is marked one foot above ground level at the stake minus the difference in the two rod readings in case the ground is highest at the stake and plus the difference if it is lower. In case the ground level at the stake is highest by more than one foot, it becomes necessary, in order to keep the reference mark above ground where it may be seen, to raise it one or more feet. In such cases its height is recorded on the stake.

Another practice requires that a mark to serve as a reference be placed on each grid-corner stake at one foot above grade. In this case it is necessary to determine grade beforehand. Thus the survey is made, the grade calculations are completed and the survey instrument is brought into the field again for the purpose of placing the one-foot-above-grade marks on the grid-corner stakes. These operations usually include several short-cuts which are designed to reduce the possibility of error and to save time. Rod readings instead of elevations are used throughout the job so that heights of ground surface and grade are expressed as rod readings. Also when the survey instrument is returned to the field it is set up at the same spot and height as before. With the instrument in this position the rod readings originally taken at the grid corners can be duplicated. It follows that one foot above grade can be located for each of the grid corners by placing the rod against the stake, raising it until the horizontal cross hair in the instrument coincides with the rod reading that is one foot less than that which represents grade at that point, and marking the stake opposite zero on the rod. If one foot above grade is lower than ground surface, the rod is raised one or more feet further before making the mark and a notation is made to that effect.

Depth of cut is indicated on stakes by marking with red color or red material the distance measured downward from the top of the stake which corresponds to the depth of cut at that point. In case the reference mark is one foot above ground level, grade is below it a distance of one foot plus the red colored portion of the stake. If the reference mark is one foot above grade, its position is all that is needed to locate grade. In both cases the length of stake colored red shows the grader operator the depth that the original ground surface must be lowered at that particular point. Also he may dismount from his machine at any time and with a foot rule which he carries for the purpose measure from the reference line to determine the exact grade. In case the depth of cut is greater than can be indicated in this manner on the four-foot lath stakes, a red arrow is marked on the stake pointing downward from the top of the stake and the depth of cut is printed in red beneath it.

Depths of fill are indicated by color-

ing solidly blue a band several inches wide around the stake immediately beneath the level designated as grade. If the reference mark is one foot above ground level and the depth of fill is less than one foot, grade is located at one foot minus depth of fill below the reference mark. If depth of fill is more than one foot, grade is depth of fill minus one foot above the reference. If reference is one foot above grade, its position is all that is needed to locate grade. In case the depth of fill is greater than can be indicated in this manner on the four-foot lath stakes, the stakes are lengthened by nailing two or more of them together.

Other markings. When the original ground surface is at grade, neither cut nor fill is called for, so the distinctive red or blue band does not appear on the grid-corner stakes at these locations. However, some other distinctive marking such as a red or blue circle with an arrow drawn through it may be used to show that the marking of these stakes was not overlooked.

To avoid the possibility of misinterpretation and to save unnecessary duplication of engineering work, the materials used for marking the stakes should be distinctive and durable. A strip of waterproof adhesive tape one-quarter inch wide wrapped around a stake serves ideally as reference. The red and blue colors are best made with lumber crayon or with paint applied with a spray gun.

Earthwork calculations can be found in the appendix on pages 41 to 44.

What You Should Know About Equipment

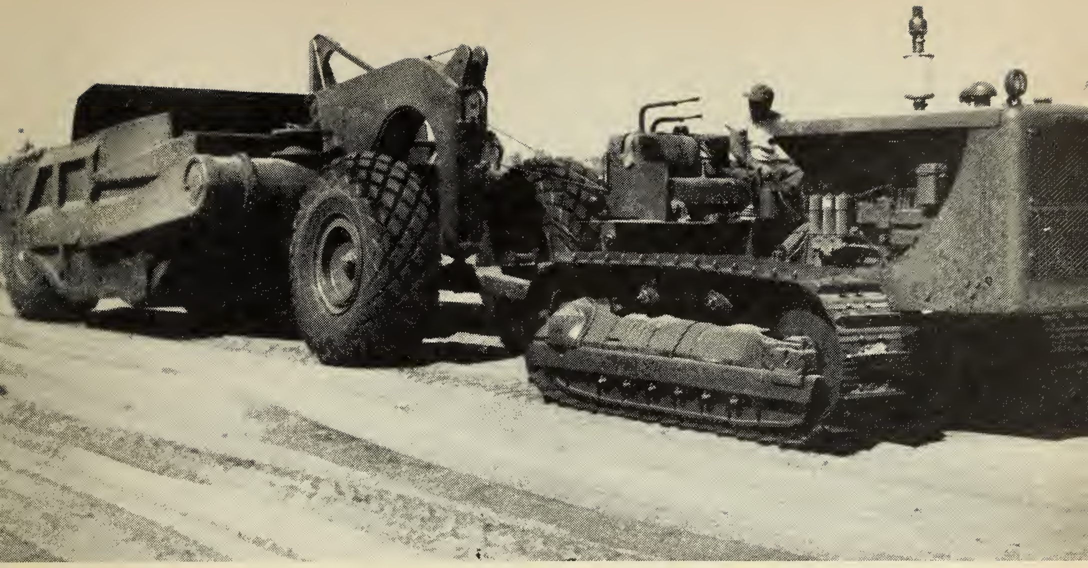
Best performance of the equipment currently used for grading land is possible only when it includes an adequate number of machines in good repair and of the type and size best adapted for handling, under the conditions encountered, each operation to be performed. Such ideal equipment make-up should be the aim, but reasonably may not or cannot be realized in all cases.

When land grading is a side issue, to be performed during spare time without hiring extra labor, a high capital investment in earth-moving equipment is neither advisable nor is such investment necessary to get the work done at a reasonable cost. If you, as a landowner, undertake this work for yourself or others, you may be in this position. With a small outfit you frequently can show good results.

Contractors who follow farm-land grading as a full-time business are in a different position. To compete successfully for jobs they should have the equipment that is capable of the highest performance. When such equipment is kept busy its ownership should be profitable. In reality earth-moving contractors are variously equipped depending on their resources and the class of earth work previously engaged in. It may be impossible to find one who possesses the full array of machines of the newest and most efficient type and size to handle a particular land-grading job. To be acceptably well equipped they should, at least, have the ordinary grader's outfit consisting perhaps of somewhat smaller and slower machines than might be best, but all in good working order, and any extra pieces of equipment for which there is special need. Frequently contractors can rent the extra pieces of equipment, or sublet the work requiring them.

Who should be concerned most with equipment suitability in case of contracted work? The answer to this question depends upon how the operation is

The following five pages contain photographs of earth-moving equipment and statements of what each machine can be expected to accomplish. ➡



CRAWLER TRACTOR

The crawler tractor is one of the important machines used for grading farm land. The main distinguishing feature, the crawler track, gives superior traction on the varying soil and ground conditions encountered in land grading. It also limits top travel speed to about five miles per hour. Thus it is more capable than other tractors of loading an attached scraper; it is essential as a pusher tractor (bottom) when extra power is required for loading; and it is the best tractor for pulling a ripper. On the other hand when it is pulling a scraper, it is limited—because of its low speed—to relatively short hauls.

RUBBER-TIRED WHEEL TRACTORS

Rubber-tired two- and four-wheel tractors are used for earth moving when the emphasis is on speed rather than drawbar pull. The two-wheel machine (top) is designed for maneuverability in addition to speed, which makes it especially adapted to highway and levee work. The four-wheel tractor (bottom) is built first for speed and second for steady performance. Either machine can be used to great advantage on land-grading jobs requiring extra-long-distance hauling.

CARRIER-TYPE SCRAPER

The carrier-type scraper is currently used on most land-grading jobs. It consists essentially of a bowl or bucket mounted on rubber-tired wheels with a blade and apron across its front end for cutting, scooping and retaining a load of earth. To load, the bowl is lowered and the apron is partly lifted. In hauling position the apron is closed and the bowl is lifted clear of the ground. To dump or spread, the apron is lifted and the load is pushed forward through the opened end of the bowl by an ejector member which normally rests against the rear of the bowl. With this one tractor-drawn implement and one operator earth is excavated, loaded, hauled and spread. The carrier-type scraper used by most contractors for grading land generally has a maximum capacity ranging from approximately 15 to 23 cubic yards. If these sizes are powered and applied properly, each larger unit will give better efficiency, more yardage and less cost per cubic yard. To be used at top efficiency, the depth of cut must be sufficient for rapid loading; the scrapers must be pulled by the right type of tractor, and if extra power can be used to advantage, they should be operated in groups with a pusher tractor.

ROTARY SCRAPER

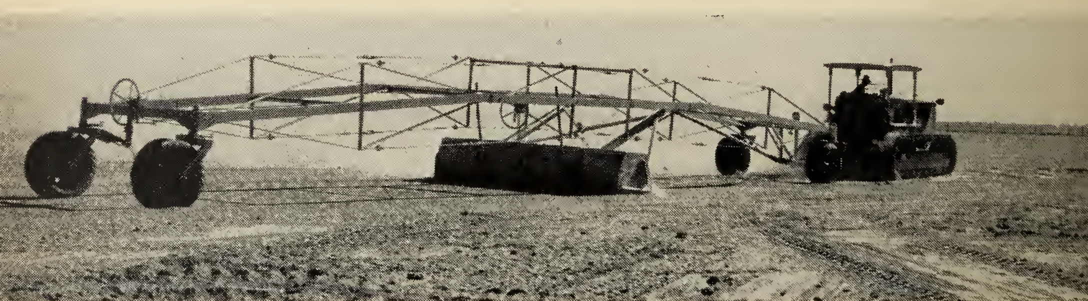
The rotary scraper works on a different principle from that of the carrier-type scraper. It consists essentially of a bladed wheel conveyor which revolves about a cylindrical bowl to remove constantly the excavated earth from the scraper blade and deposit it into the top of the bowl. The bowl revolves to unload. It has a lower production rate and is less durable for rugged service than the carrier-type scraper. On the other hand, it requires much less power to operate than the carrier-type scraper, and it will load to capacity as readily when the depth of cut is extremely light as when it is optimum. These features make rotary scrapers especially suitable for light work with farm-size tractors.

BOTTOMLESS SCRAPERS

Bottomless scrapers represent two types of equipment which are designed to remove small grade irregularities. As the name implies the bowl or bucket has little or no bottom and earth moving is accomplished with them by scraping up a load, dragging it a short distance and dumping it. To perform these operations well with this type of machine the ground surface must be broken first or the soil must be of a loose texture. A machine of this type is essential for the finishing work on land that is being graded to an even slope of from 0.2% to 0.3% or less. It also helps prepare a seed bed through the pulverizing effect of a rolling action of the scraper load as it is dragged.

The bottomless scraper with the long frame is one of several makes which is designed to work automatically. It is currently manufactured in lengths up to 80 feet and widths up to 15 feet. The blade is attached to the frame midway of its length at a height which is adjustable. It is mounted on swivel wheels to make it less unwieldy to turn. When in use the blade is permanently set at a level which will maintain about one-third of a load in the bowl. With this adjustment properly made the machine will, as it is drawn across a field, automatically remove high spots and fill depressions of a diameter equal to nearly one-half its length. Obviously the longest machine available will perform the best. It is customary to take care of the final finishing work with a machine of this type by scraping in three directions—in each of the two diagonal directions and in the direction of irrigation. The operation is termed land planing.

The two-wheel bottomless scraper, better known as a drag scraper, is sometimes used ahead of land planing to remove surface irregularities too large to be planed out and too minor to be taken care of economically with a carrier-type scraper. This machine is manufactured in a number of widths to serve various purposes including the extra widths of 12 to 18 feet for rapid handling of light land grading. It is operated to cut and to drag and drop its load by the tractor driver through hydraulic controls. The accuracy with which this must be done calls first of all for an operator who is expert in handling one of these wide drag scrapers.



CHISELS AND RIPPERS

Chisels and rippers are tractor-drawn implements that are sometimes used to break hard soil or subsoil prior to earthmoving. If the surface soil is hard and requires loosening in order that a satisfactory earth moving production rate can be maintained, chiseling will suffice. The implement to use in this case is similar to the one with eight or ten teeth 12 inches or so long mounted on a relatively light carrier. If hard subsoil or hard claypan is to be dealt with, ripping may be called for with the much stronger and heavier implement weighing up to 3 or 4 tons and usually equipped with no more than 2 or 3 teeth from 24 to 36 inches long. It should be determined beforehand that these operations will not increase the uncertainty of how much allowance should be made for the settlement of fills. Any increase in the cloddiness of the soil will have that effect. Chiseling or ripping may be desirable, after land has been graded, to effect needed improvement in water intake rate and depth of root penetration.

to be paid for. Obviously, when work is let by the cubic yard of excavation or by the job, it is to the interest of the contractor to be mechanized for the purpose as efficiently as possible. If you, on the other hand, hire the work done by the tractor hour, you bear the unnecessary expense due to unsuitable equipment. In selecting a contractor who is satisfactorily equipped for the particular job, you will act wisely if you know something about the advantages and limitations of at least the principal machines used for grading farm land.

Crawler vs. Rubber-Tired Wheel Tractor-Scraper Units

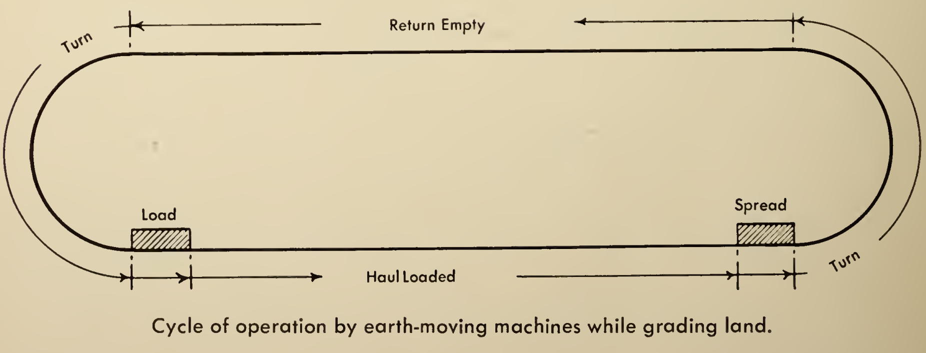
Tractor-scraper units are usually operated on a cycle. A carrier-type scraper is loaded, hauled loaded, unloaded, turned, hauled empty, and turned to be ready for loading again as shown in the diagram on this page. If the depth of excavation is sufficient for efficient loading, this operation is performed in approximately one minute and by 100 feet of scraping. This time will be the same for any properly matched, pusher tractor aided, tractor carrier-type scraper unit. Likewise the time required for turning and unloading is practically the same for all units since these operations are performed at relatively slow speeds. There remains in the cycle the time required for hauling. Obviously this varies greatly with the haul distance and the speed of the haul tractor. All tractor-scraper units have a lower production rate and a higher cost per cubic yard of earth moved as the haul distance increases. Hence it is desirable to keep the haul distance as short as possible. The maximum one-way haul distance allowed frequently ranges up to one-fourth mile and in some cases extends to one-half mile.

Obviously there is a haul distance for each set of ground surface conditions beyond which it is economical to switch from the slow traveling crawler tractor unit to the high speed rubber-tired wheel equipment. How this distance is determined is shown in greater detail in the appendix on pages 45 and 46.

Equipment for Shallow Grading

Sometimes farm land grading calls for depth of cut ranging mostly from 0.1 to 0.4 foot. When such slight cuts are the rule, earth moving is slow work and may cost from one-fourth to one-half more per cubic yard than when a greater volume of earth is moved. Contractors appraise a job in this respect by the average yardage of excavation per acre. Two hundred cubic yards per acre or less is considered costly per cubic yard; from 400 to 500 average; and from 800 to 1,000 low-unit cost work.

When carrier-scraper equipment is being used for shallow grading the production rate decreases and the unit cost of earth moving goes up for two reasons. First, too little earth is available to load the scrapers efficiently, i.e., loading



Cycle of operation by earth-moving machines while grading land.

cannot be completed in one minute and during 100 feet of scraping. Second, particularly where the soil is sandy, or light weight and fluffy as are some alkali soils, the cut earth tends to push ahead and spill to the side of the scraper instead of rising on the blade and entering the bowl, thus making it impossible or uneconomical to obtain a capacity load.

Most contractors and manufacturers of earth-moving machines affirm that even with these handicaps carrier-scraper equipment can be depended upon for the best performance to be had. With few exceptions the same rules apply, they say, as when the depths of cut are sufficient for efficient loading. The extra cutting width of the largest carrier-scraper units and their relatively low unit production cost for an operator usually more than offset their higher cost of ownership. Furthermore, the great weight of these machines makes is possible to hold closer to grade than might otherwise be done while removing a thin layer of earth from a hard ground surface. Some old model, large carrier-type scrapers are extra wide and for this reason are highly rated for this class of work. The all rubber-tired wheel equipment continues to be superior to the crawler-tractor scraper unit for haul distances in excess of about 500 feet. However, the four-wheel instead of the two-wheel tractor is best to use in this case because its steadier performance allows closer adherence to grade while shallow cuts are being made. Pusher tractors are generally not required for shallow grading.

Since plus or minus 0.1 foot is the generally accepted tolerance for rough grading, it may be seen that a considerable part of what is termed here "shallow grading" is considered impractical work for carrier-type scrapers. To finish properly a job of rough grading and perhaps also to do work initially consisting entirely of shallow grading calls for the bottomless scraper equipment and possibly the rotary type scraper. Many landowners arrange to equip themselves with bottomless scrapers or rotary type scrapers and to do shallow grading, or the finishing work during their spare time.

Suggestions for Contracts and Specifications

Most land grading work is let according to verbal agreement as to price and how well the land will irrigate after it is graded. Many misunderstandings arise due to such informality and some injustice is done for which there is no recourse. The lack of detailed written contracts is due at least in part to the absence of standards to follow. In the interest of promoting the preparation and acceptance of such standards the following suggestions are offered.

Written contracts may be entered into either with or without prior invitation and acceptance of bids. In the opening paragraph of the contract give the date of the agreement and names of the parties and state that the agreement is made between those persons on that date. After naming the person who undertakes to perform the engineering or land grading services, include "hereinafter called the contractor," and after naming the landowner or other person for whom the work is to be performed, include "hereinafter called the landowner," and throughout the remainder of the contract refer to the parties by those terms. The body of the contract will consist of paragraphs or clauses covering all specific items of the agreement. End the contract with the signatures of the parties, each one followed by "contractor" or "landowner" as the case may be.

Engineering Contract

In the usual case the engineering contract will not involve calling for bids. If bids are not called for, the landowner is justified in requiring the intending contractor to furnish evidence of his capability including references and a statement of his experience. If bids are invited, each bidder should be required to furnish such evidence of capability when submitting his bid proposal.

When staking, surveying, mapping, calculating cut and fill quantities, posting of grades, and grade checking for proof of satisfactory completion of construction work are services to be rendered, the provisions in a written engineering contract should include:

1. *Description of site conditions* including location, acreage, vegetal cover, and ground surface.

2. *Any particular kind of construction* that the landowner wishes to specify such as: subdivision of property into fields; direction, uniformity, and degree of land slope; locations, heights and widths of ribbon fills for irrigation ditches and roads; locations and carrying capacities of drainage ways; etc.

3. *Any particular requirement*, procedure or method the landowner wishes to impose with regard to the staking, surveying, mapping, allowance for settlement of fills, grade calculations, computation of quantities, etc. (See pages 32 to 46).

4. *Facilities, materials and assistance* which will be available to the contractor.

5. *Date* when the job must be ready for construction.

6. *Delivery of map.* The requirement that the map or maps of the project be delivered to the landowner showing the original elevations and contours, locations of all proposed ribbon fills and drainage ways, and the depths of cut or fill to be made at each grid corner.

7. *Yardage estimates.* Provision requiring the contractor to determine and make available, if judged necessary by the landowner, the following quantities (cubic yards) of each excavation:

   a. Total for entire area to be graded.

   b. Total for all isolated areas in which the cuts are mostly shallow and amount to 200 or less cubic yards per acre.

   c. Total for all isolated areas in which the cuts are mostly medium and amount to between 200 and 500 cubic yards per acre.

   d. Total for all isolated areas in which the cuts are mostly heavy and amount to more than 500 cubic yards per acre.

   e. Total in areas of cut which lie within 500 feet of areas of fill to which the earth will be moved.

   f. Total in areas of cut which lie more than 500 feet from and within 1,200 feet of areas of fill to which the earth will be moved.

   g. Total in areas of cut which lie more than 1,200 feet from areas of fill to which the earth will be moved.

8. *Cut vs. fill estimates.* Agreement to supply to the landowner the total volume of cut in terms of per cent of the total volume of fill which is estimated to be required and which is used for computing the quantities of earth excavation and/or cost of grading.

9. *Follow-up engineering.* Assurance that the contractor will promptly make necessary adjustments of the posted cuts and fills, replace grade stakes that are knocked down, and check the grades for proof of completion of construction.

10. *Liability insurance.* Proof that the contractor carries sufficient liability and/or compensation insurance to cover his full liability under the "Workmen's Compensation Insurance and Safety Act."

11. *Payment schedule.* Usually the cost will consist of the hourly wages for engineer and each assistant, plus transportation and possibly other expenses and will be billed for by the month or by the job. Occasionally a stipulated price per acre is the basis for settlement.

Contract for Rough Grading

The operation whereby a land surface is brought sufficiently close to a prescribed grade to permit satisfactory completion by floating or planing is termed rough grading. It is desirable in many situations to invite bids for rough grading work, reserving the right to reject any and all bids. Each bidder should be required to submit evidence that his previously performed land grading work has been satisfactory. The successful bidder to whom the award is made, enters into a contract with the landowner which comprises a written agreement and the written conditions and specifications and the drawings that have been made available to intending bidders. The written agreement is based upon the offer and acceptance of the bid and specifically makes the conditions, specifications, and drawings a part of the contract.

The following suggestions assume a call for bids, award to a bidder whose proposal meets the landowner's requirements, and execution of the written agreement noted in the immediately preceding paragraph. The suggestions, however, may be adapted to the execution of a written contract without bids by considering all matters of pre-bid procedures in the suggestions as simply part of the informal negotiations that lead up to the signing of the contract.

Bids for rough grading usually can be obtained by the tractor hour, by the cubic yard of earth excavated, or by the job.

If payment is made by the tractor hour, the following items should be included in the contract:

1. *Description of work* including location, vegetal cover, topography, soil type, acreage, and total cubic yards of earth excavation. The instruction to the bidders should explain that interested bidders will be expected to visit the property and will be responsible for accurate appraisal of site conditions.

2. *Time schedule,* including required starting and completing dates, with provisions for (a) extensions of time granted by the landowner because of delays not caused by the fault of the contractor, (b) for liquidated and ascertained damages for failure to complete the work within the time specified or within extensions of time so granted, and (c) for a performance bond. It is suggested that the liquidated and ascertained damages for each day that the work remains incomplete be fixed at not to exceed $25 per day in most single-farm grading contracts. With large jobs, for example where the contract amount exceeds $25,000, $50 per day would be appropriate.

3. *Cessation of grading operations for wet soil.* Most soils would be damaged if graded during wet weather or while remaining wet. The landowner should have the right at such times to direct when work must stop and when it may start, subject to the adjustment of the specified time for completing the work thus made necessary.

4. *Preliminary chiseling.* Cloddy fill material should be avoided as much as possible by specifying whether chiseling may or may not precede scraping.

5. *Placement of fill material.* It is desirable to require that cloddy soils be spread in thin (approximately 4 inches) layers to avoid as much as possible unpredictable settlement.

6. *Equipment suitability.* A sufficient description of each piece of equipment which it is proposed to use on the job should be called for to show whether or not the equipment layout meets the requirements of the work to be performed.

Furthermore the landowner should reserve the right during the progress of the work to stop any operation or the use of any machine which in his judgment is inefficient.

7. *Time clocks.* The contractor should be required to equip all tractors used on the job with accurate time clocks and to keep an accurate record of the time actually worked by each machine and to furnish the landowner copies of such records.

8. *Time to be paid for.* It should be explained in the contract that payment will be made for only the time spent while the equipment is at work. Time used in transporting the machines to and from the job and for their repair and servicing should not be considered as working time to be charged to the landowner.

9. *Damage due to grading operations.* The contract should state that the contractor will be required to pay the cost of repairs and replacements necessitated by damage from grading operations, including that for resetting necessary grade stakes which are knocked down.

10. *Final clean-up.* Contractor should be held responsible for cleaning the field and all grounds occupied by him in connection with the work of all rubbish, excess material and equipment.

11. *Insurance.* Contractor should be required to submit proof that he carries sufficient liability and/or compensation insurance to cover his full liability under the "Workmen's Compensation Insurance and Safety Act."

12. *Payment schedule.* This should include the right of the landowner to withhold final payment of 10 per cent to the contractor for 35 days after the recording of "notice of completion of work," provided that the landowner records the notice with the county recorder within 10 days following the date of completion of the work. This provision is necessary to protect the landowner in the event that labor or material liens are filed against his land. It is provided by statute in California that if the landowner records the notice of completion of work within the 10 days, liens may be filed only within the 30 days next following the date of recording. Thirty-five days, however, is considered necessary to provide a proper factor of safety. For work done outside of California, the applicable State statute should be consulted.

If payment is made by the cubic yard of earth excavation it is suggested that items 1 to 5 remain the same as for the preceding contract and that the following be added.

6. *Basis of measurement for payment.* For payment purposes a cubic yard of earth excavation is a cubic yard of earth in place, or before it is moved. Earth in areas of cut which is either excavated below or left above grade should not be included.

7. *Computation of earth quantities.* Since earth quantities can be computed several ways with different results, it is important to specify the method which is used. The dependable fair accuracy that can be obtained with the average end areas method commends its use when payment is made by the cubic yard of earth excavation.

8. *Class of earth excavation.* Total yardage of earth excavation should be stated if possible for the bidder's benefit in the three categories called for by items 8-b, 8-c and 8-d of the engineering contract. It should be explained that these quantities are approximate and tentative and that the landowner assumes no responsibility for their accuracy.

9. *Lengths of haul.* The difficulty of identifying specific lengths of haul in land grading work discourages recognition of haul distance as a measurement for specifying different payments for moving a cubic yard of earth. Instead, the effect of haul distance is usually left for the bidder to appraise. To this end

he must be granted the right to study the project map and to use it in event his bid is accepted. Furthermore he should be given the approximate yardages of earth excavation for the three haul distances listed in items 8-e, 8-f and 8-g of the engineering contract. It should be explained that the landowner assumes no responsibility for the accuracy of these figures.

10. *Ceiling on total cost.* Owing to sometimes wide discrepancy in the amount of earth excavation used by diferent contractors to complete their work, it is desirable and equitable in order to insure careful earth moving and a reasonable total cost of grading to place a limit for payment purposes on the amount the volume of cut may exceed the volume of fill (see pages 17 and 18).

11. *Grade tolerance.* In case the slope of the graded surface is around 0.2 per cent, as most often is the case, the tolerance should generally not exceed one-tenth of a foot above or below the prescribed grade as determined by nine readings in each grid square, i.e., one at each corner, one on each side midway between corners, and one at the center. Greater deviations are permissible if they are confined to areas of not to exceed 400 square feet. Relatively greater departures from a prescribed grade may be allowed for steeper slopes.

12. *Damages due to grading operations.* Same as Item 9 for contract B.

13. *Final cleanup.* Same as item 10 for contract B.

14. *Insurance.* Same as item 11 for contract B.

15. *Payment schedule.* Same as item 12 for contract B.

If payment is made by the job, items in the contract should be the same as for the preceeding contract except that items 6, 7 and 10 do not apply.

Contract for Fine-Finish Grading

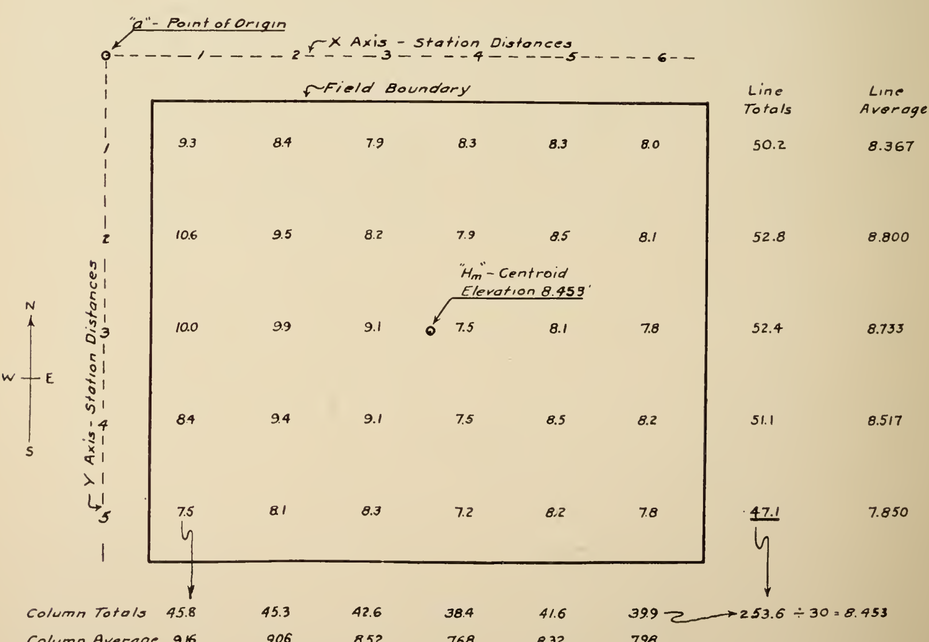
If rough grading is completed as should be, to the proclaimed tolerance and the fine finish work remains to be let, a very simple contract or none at all will suffice. The required work consists of planing the ground surface in a sufficient number of directions with a machine which is designed to remove automatically the grade irregularities in small areas allowed during rough grading. Thus the length of planing machine and the directions to be planed should be specified or understood. The work is usually contracted for either by the hour, or by the acre for each planing.

APPENDIX

I. Methods of Land-Grading Calculations

Least-Squares and Average Profiles Method. The least-squares method is a statistical procedure for obtaining the best fit to a group of points. It was first adapted to the problem of fitting a plane to the different elevations delineating an uneven land surface of a rectangular tract of land (C. V. Givan, Land grading calculations, Agr. Engin. 21(1): 11–12, 1940). Later its application was extended to include land areas of any shape (G. E. Chugg, Calculations for land gradation, Agr. Engin. 28(10) : 461–463, 1947). The least-squares and average profiles method is another adaptation of the same principle to the problem which appears to be sufficiently easy to follow and practical to use to warrant wide acceptance. The solution consists of changing the problem from one of fitting a plane by the least-squares method to a large number of grid corner elevations, which has been the procedure proposed by Givan, to the simpler computation of determining by the method of least squares the slopes of the lines which most nearly fit the average profiles in the two coordinate directions. It will be shown later how the slope of these two lines are used to form a plane which, when properly placed, fits the contour pattern best. The following example explains the method and shows how the calculations are made.

Let it be assumed that the chart below is the base map of a rectangular area which is to be leveled as a unit. The stakes are set and the elevations are given at 100-foot intervals starting 50 feet in from the property lines, thus forming a grid with the elevation known at each grid corner. For grade calculation purposes the



Base map showing the land elevation at grid corners, the location and elevation of the centroid, the average profile figures, and the point of origin of the plane to which the field is to be graded.

grid corners are located by a system of coordinates. In this case the point of origin "a" is located 50 feet north and 50 feet west of the northwest corner of the field. The locations of the grid corners are designated in stations (number of 100-foot intervals) southward along the Y axis and eastward along the X axis from "a." The position of the point with elevation 9.9 would thus be 2 stations east and 3 stations south of "a."

The first step in the calculations consists of adding the elevations along each line and in each column as shown on the map and computing the average elevation of each line and each column. The average elevation changes from north to south and from west to east across the field are thus shown by the line and column averages respectively.

The second step consists of locating the centroid, "H_m," and determining its elevation. The centroid is the exact center of the grid. Its elevation in this case is the average of all the grid-corner elevations. If the outside grid corners are spaced other than one-half the interval between grid corners from the boundaries of the field, or so the elevation of each grid corner applies to different size areas than 10,000 square feet, the elevations of these points must be weighted for determining H_m in accordance with the land areas represented by each of them. This point determines the position in elevation of the plane which best fits the contour pattern. The location of H_m is its average station distances from "a" on the X and Y axes, or X_m and Y_m. X_m and Y_m for the problem being presented thus would be:

$$X_m = \frac{1+2+3+4+5+6}{6} = 3\tfrac{1}{2}\text{; and } Ym = \frac{1+2+3+4+5}{5} = 3$$

The third step consists of determining slopes of the lines which most nearly fit the average profiles in the two coordinate directions. At this point it is desirable for the purpose of illustration to plot the average line elevations and the average column elevations as shown in the two graphs on page 34. To avoid confusion with the diagram on page 32, the coordinates for these two graphs are designated as H for elevations and S for distance in stations from the point of origin "a." According to the least squares method, the slope of the line which best fits the points on each of these two profiles is:

$$G_{NS} \text{ or } G_{WE} = \frac{\Sigma(SH) - \dfrac{(\Sigma S)(\Sigma H)}{n}}{\Sigma(S)^2 - \dfrac{(\Sigma S)^2}{n}}$$

where G_{WE} = Slope of the line which best fits the points which represent the average land slope in a west to east direction across the field.

G_{NS} = Slope of the line which best fits the points which represent the average land slope in a north to south direction across the field.

Σ = The sum of a number of values.

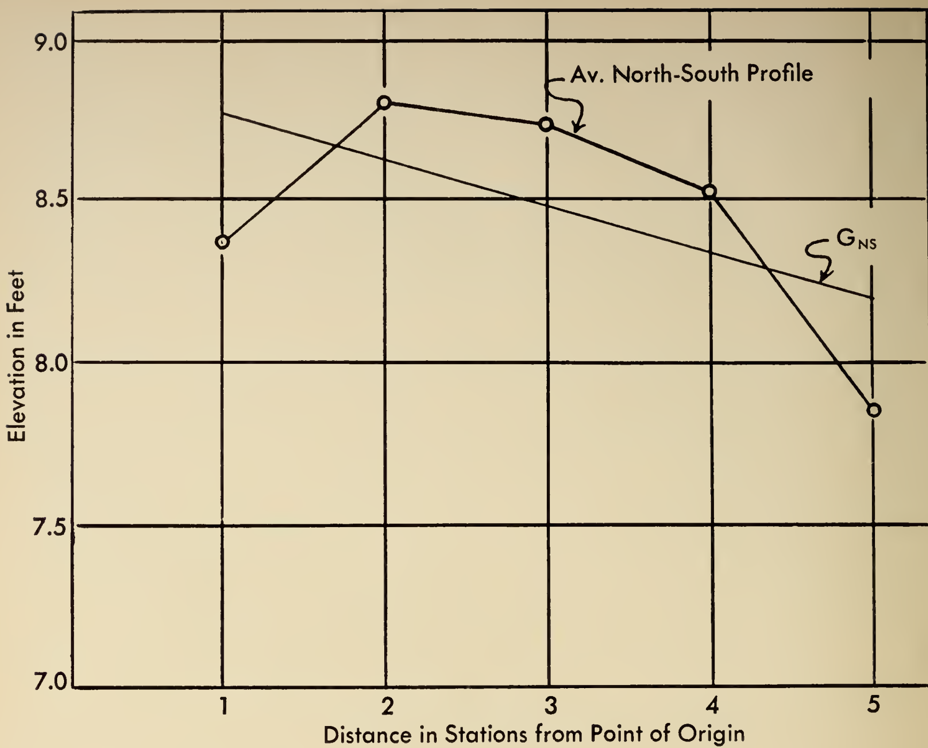
$\Sigma(SH)$ = The sum of the products of the station distance and elevation of each of the plotted points on each of the graphs on page 34.

$\Sigma S \Sigma H$ = The product of the sums of the station distances and the elevations of each of the plotted points on each graph.

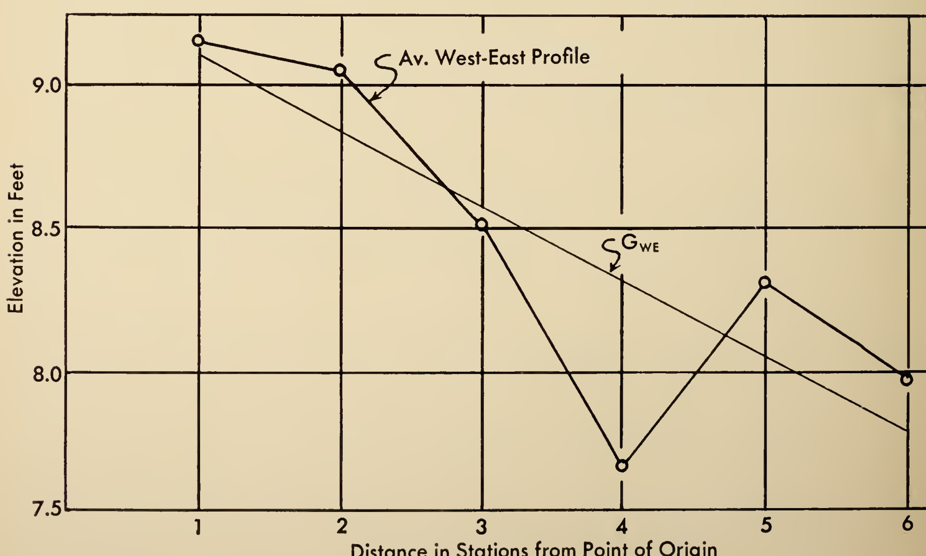
n = The number of plotted points on each graph.

$\Sigma(S)^2$ = The sum of the squares of the station distances of each of the plotted points on each graph.

$(\Sigma S)^2$ = The square of the sum of the station distance of each of the plotted points on each graph.



Average land profile from north to south (top) and from west to east (bottom).



The G_{NS} and G_{WE} slopes for the problem being presented are thus computed as follows:

Computation of G_{WE} or the slope which best fits the original topography in a west to east direction across the field

$$\begin{aligned}
\Sigma(SH) &= (1 \times 9.16) + (2 \times 9.06) + (3 \times 8.52) + (4 \times 7.68) + (5 \times 8.32) + (6 \times 7.98) \\
&= 173.04 \\
\Sigma S &= 1 + 2 + 3 + 4 + 5 + 6 \\
&= 21 \\
\Sigma H &= 9.16 + 9.06 + 8.52 + 7.68 + 8.32 + 7.98 \\
&= 50.72 \\
\Sigma(S)^2 &= 1 + 4 + 9 + 16 + 25 + 36 \\
&= 91 \\
n &= 6
\end{aligned}$$

$$\text{Then } G_{WE} = \frac{173.04 - \dfrac{21 \times 50.72}{6}}{91 - \dfrac{(21)^2}{6}}$$

$= -\,0.256'$ per 100 feet. (Minus sign indicates slope is eastward from "a")

Computation for G_{NS} or the slope which best fits the original topography in a north to south direction across the field

$$\begin{aligned}
\Sigma(SH) &= (1 \times 8.367) + (2 \times 8.80) + (3 \times 8.733) + (4 \times 8.517) + (5 \times 7.850) \\
&= 125.484 \\
\Sigma S &= 1 + 2 + 3 + 4 + 5 \\
&= 15 \\
\Sigma H &= 8.367 + 8.80 + 8.733 + 8.517 + 7.850 \\
&= 42.267 \\
\Sigma(S)^2 &= 1 + 4 + 9 + 16 + 25 \\
&= 55 \\
n &= 5
\end{aligned}$$

$$\text{Then } G_{NS} = \frac{125.48 - \dfrac{15 \times 42.267}{5}}{55 - \dfrac{(15)^2}{5}}$$

$= -\,0.131'$ per 100 feet. (Minus sign indicates slope is southward from "a")

The time required for computing G_{NS} and G_{WE} will be reduced materially by tabulating for use as in the table below all possible values for $\frac{\Sigma S}{n}$ and $\Sigma(S)^2 - \frac{(\Sigma S)^2}{n}$.

It is also of some practical importance to note that G_{NS} and G_{WE} may be determined without the least squares computations by merely fitting a line as closely as can be determined by inspection to each of the two average profile graphs on page 34. The slopes of these lines expressed as the difference in elevation per station distance are then assumed to be G_{NS} and G_{WE}. Ability to approximate in this manner the results obtained by least squares depends largely on the shape of the profiles. If the lines can be placed on the profiles with fair confidence that they approach closely the best fit and if some practice is had with duplicating in this manner the results obtained by least squares, the error involved in using this short cut may be small.

The fourth step consists of using slopes G_{NS} and G_{WE} and the elevation of the centroid to delineate the plane which best fits all of the grid-corner elevations in the diagram on page 32. To this end the known values for G_{NS}, G_{WE}, and H_m are substituted in the equation for a plane to determine the elevation at the point of origin, "a." Then the new elevation for each of the grid corners is found by adding algebraically the elevation at the origin and the product of the slope and distance in stations in both coordinate directions, thus:

The equation of the plane is: $H_m = a + (G_{WE})(X_m) + (G_{NS})(Y_m)$ in which H_m = elevation of the centroid

n	$\frac{\Sigma S}{n}$	$(S)^2 - \frac{(\Sigma S)^2}{n}$	n	$\frac{\Sigma S}{n}$	$(S)^2 - \frac{(\Sigma S)^2}{n}$
2	1.5	0.5	15	8.0	280.0
3	2.0	2.0	16	8.5	340.0
4	2.5	5.0	17	9.0	408.0
5	3.0	10.0	18	9.5	484.5
6	3.5	17.5	19	10.0	570.0
7	4.0	28.0	20	10.5	665.0
8	4.5	42.0	21	11.0	770.0
9	5.0	60.0	22	11.5	885.5
10	5.5	82.5	23	12.0	1012.0
11	6.0	110.0	24	12.5	1150.0
12	6.5	143.0	25	13.0	1300.0
13	7.0	182.0	26	13.5	1462.5
14	7.5	227.5			

a = elevation of the point in the plane at the origin
X_m and Y_m = the horizontal and vertical coordinates of Hm
G_{NS} and G_{WE} = slopes of the plane in the Y and X directions respectively.

In the diagram on page 37, $H_m = 8.453$

$$X_m = 3.5$$
$$Y_m = 3$$

Thus,

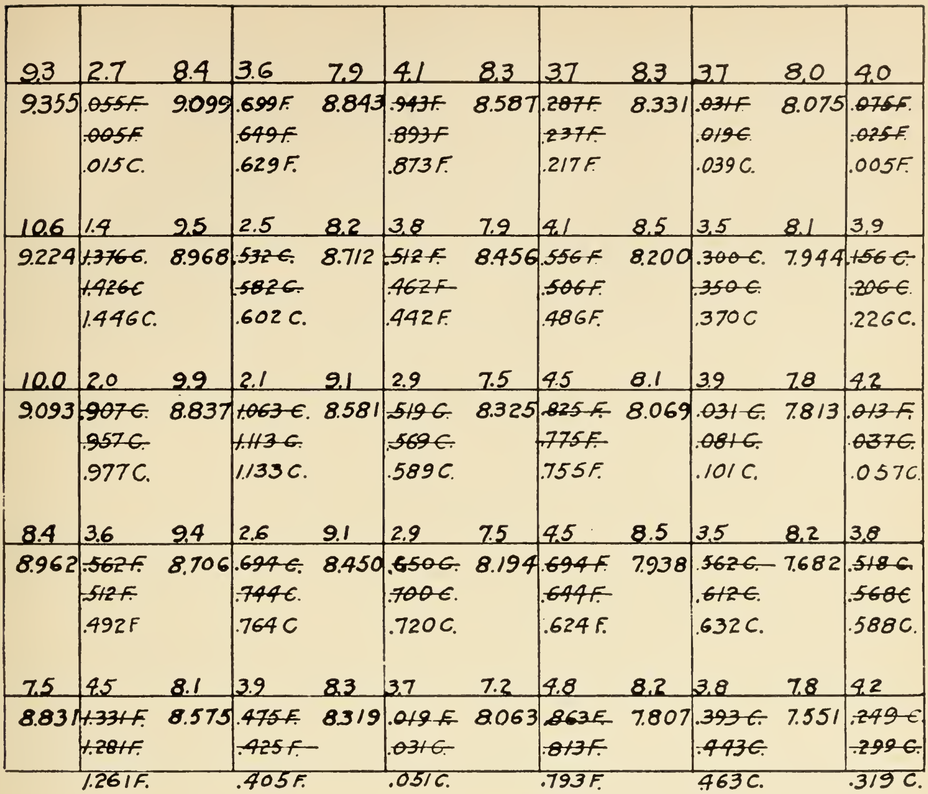
$$a = 8.453 - (-0.256 \times 3.5) - (-0.131 \times 3)$$
$$= 9.742$$

The new elevation that would correspond with the old elevation 9.9, three stations south and two west of point of origin a, would then be found as follows:

$$H = a + (G_{WE})(X) + (G_{NS})(Y)$$
$$= 9.742 + (-0.256 \times 2) + (-0.131 \times 3)$$
$$= 8.837$$

If these calculations are completed to the third significant figure beyond the decimal, the resulting plane will require almost exactly the same amount of cut as fill and the total amount of earth moved will be a minimum.

Most irrigated fields are suitably shaped for using the methods of grade calculation so far explained. That is, they are four-sided with opposite sides approximately parallel. G. E. Chugg in the before-mentioned publication describes a precise method of calculation for also fitting a plane to the topography of an irregularly shaped field. Unfortunately, however, his method has proved too intricate to be adopted generally to land grading and no way has been found to simplify it. So, as a general practice to follow in such cases it is recommended: First, that the best coverage possible, of



Map showing elevations and cuts and fills. It contains three sets of figures representing either cuts or fills at each grid corner. The top row of figures represent the cuts and fills as would be calculated by the least-square method. The second row represents the cut and fills when all elevations are lowered 0.05 foot. The third set of figures represents the cut and fills when all elevations are lowered 0.07 foot. The latter set of figures is presumed to give the required excess volume of cut.

the land to be graded as one field, be obtained with one or more of the four-sided areas. Second, that the previously described procedure for determining G_{NS} and G_{WE} be employed. Third, that the slopes so determined be extended arbitrarily beyond the four-sided areas to the boundaries of the property to be leveled. Fourth, that sharp changes in slope, due to subdivision of a field into more than one part and determination of G_{NS} and G_{WE} separately for each part, be modified by merging the slopes into each other.

It will be found in some instances that slopes calculated by the least squares average profiles method are either too flat or too steep to suit the crop or preferred method of irrigation. In such cases another plane which passes through the centroid but has the different desired slope may be adopted. It will be understood that any change of this kind will increase the amount of earth to be moved and also the length of haul.

The least squares average profiles method of calculating land grades is serviceable only when the lay of the land, depth of soil and other factors favor grading to a plane or a series of planes which may be merged with slight grade change one into

the other. Otherwise it is necessary to adhere closer to the original topography than can be done with a plane. This may be accomplished by using the cross-section and two-way profile methods of determining the grades.

Cross-Section Method: The following steps are necessary when the cross-section method is used:

1. Profiles of each grid line paralleling the direction of irrigation are constructed.

2. Grade lines are tentatively fitted to each of these profiles. This is accomplished by placing a straightedge on each profile to represent a possible grade line and shifting it so that the areas above it and below the ground profile properly balance those below it and above the ground profile. The slope of these lines may not be uniform and it may vary from one line to another, but it must be kept within the allowable limits for irrigation as indicated in the table on pages 6 and 7.

3. The elevations along these tentative grade lines are noted and used to plot profiles in the other coordinate direction. This second set of profiles must satisfy the cross-grade limitations listed in the table on pages 6 and 7.

4. If it is found necessary, the first set of grade lines are altered until the corresponding profiles in the other coordinate direction are satisfactory. Considerable shifting of grade lines may be necessary in order to accomplish this purpose. In the end the grade lines will delineate a land surface which will be satisfactory though probably less than ideal for irrigation.

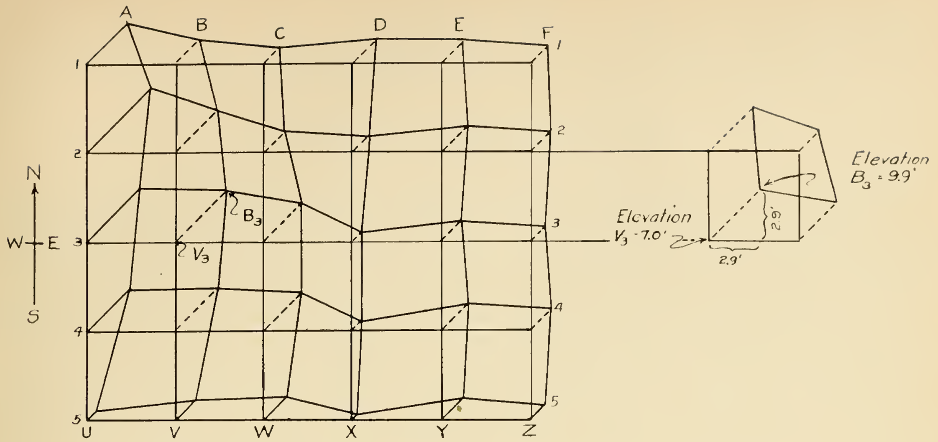
5. The differences in elevation of the original ground surface and the approved grade line along these profiles at the points which correspond to the grid corners are observed and recorded on the base map as cuts and fills.

6. The depths of cut and fill so obtained are adjusted in the same manner as for the least squares and average profiles method to obtain the proper balance between volume of cut and volume of fill.

A long narrow field in which both the most earth moving and the direction of irrigation are crosswise of the tract is especially easy to handle by this method. Small triangular or extremely irregular fields to which it is difficult or impossible to fit rectangular grids likewise can be dealt with in this way. On the other hand, use of the cross-section method for large areas should be avoided. With such areas this trial and error procedure becomes too involved to be practical. Instead the two-way profile method can be used to better advantage.

Two-Way Profile Method: The advantage to be gained by using the two-way profile method is that both the irrigation and cross grades are fitted to the original ground surface simultaneously. The following steps explain how this is done.

1. A relief map or two-way profile of the ground surface must first be prepared. This is accomplished as shown in the diagram on page 39. The base for this map, $U_1Z_1Z_5U_5$, consists of a plane with an elevation of 7.0 feet which, it is estimated, will be lower than any point in the area after the grading. The map represents a field 500 feet by 600 feet staked off as a grid in 100-foot squares. The ground surface, $A_1F_1A_5F_5$, is plotted relative to this base by subtracting the elevation of the base from the elevation of each grid corner and laying off the difference first horizontally to the right and then vertically from the position of each respective grid corner on the base. For example, to plot the ground surface B_3, which is 150 feet east and 250 feet south of the northwest corner of the field, subtract 7.0 feet, the elevation of the base, from 9.9 the elevation at B_3. This 2.9-foot difference is measured off first to the right and then up from V_3 to locate B_3. The scale used for plotting these ground



Technique employed in drawing a relief map when two-way profile method of calculating grades is used.

surface points must be large compared to that of the base in order to give necessary prominence to variations in elevation along the two-way profiles, 20 times in this case. The lines joining the points so plotted, as A_1A_5 joining the points $A_1A_2A_3A_4A_5$ and A_2F_2 connecting points $A_2B_2C_2D_2E_2F_2$, form the ground surface profiles in the two directions, or the two-way profiles.

2. The direction of irrigation is determined by studying the two sets of profiles on the two-way profile map. Grade lines are temporarily fitted to a sufficient number of individual profiles in each of the two directions to discover approximately what slopes can be made available. The direction of irrigation usually will be that of the most favorable slope.

3. With the direction of irrigation known and the two-way profile available, the next step consists of fitting simultaneously to the profiles the grade lines which suit the requirements of the irrigation slope in the one direction and the cross slope in the other.

If it is required by site conditions or need to keep land grading costs at a minimum, the slopes in both of these directions are made to follow as closely as may be the original ground surface. The grade in the direction of irrigation may be altered slightly at any grid corner so long as the slope is not reversed and is neither steeper nor flatter than is specified in the table on pages 6 and 7. The cross slope also may be changed at successive grid corners, and it is important only to see that it does not exceed the maximum allowable for the irrigation method to be used.

If site conditions and land grading costs permit, it is more desirable to have the grade uniform at least in the direction of irrigation. This is done by fitting to the successive profiles in the direction of irrigation uniform grade lines which are sufficiently near the same slope and elevation to provide a cross grade which in no place is excessive.

4. Just as with the cross-section method, the cuts and fills are first scaled from the profiles and then adjusted to obtain the proper balance between the total volumes of cut and fill.

II. Computation of Cut and Fill Adjustments

If it is estimated that 30 per cent more cut than fill is needed, it follows that the total volume of cut must equal 130 per cent of the total volume of fill, or

$$\frac{\text{Total Volume of Cut}}{\text{Total Volume of Fill}} \times 100 = 130\%$$

If the grid system is laid out as in the diagram on page 37 with the outside grid corners one-half the interval between grid corners from the boundaries of the field, or so the elevation of each grid corner applies to the same size area (10,000 square feet) it is sufficiently true for this purpose, as will be shown later, to assume that the sums of the depths of cut (Σ Cut) and fill (Σ Fill) at all of the grid corners are proportionately the same as the total volumes of cut and fill. If any of the outside corners represents a different size area than that of the inside corners, the depths of cut or fill at these points must be weighted accordingly to make Σ Cut and Σ Fill equivalent to the approximate total volumes of cut and fill. The preceding formula thus may be simplified to:

$$\frac{\Sigma \text{ Cut}}{\Sigma \text{ Fill}} \times 100 = 130\%$$

Hence, the depths of cut and fill first obtained by subtracting the original elevation of each grid corner from the corresponding calculated or graphically determined elevation, or vice versa, are totaled and the percentage difference computed. It is known by this step how cut and fill, as first determined, balance. If the total depth of cut is found to be too small to agree with the estimated requirement, the calculated or graphically determined elevation at all grid corners is lowered by trial and error an amount which will increase the cuts and decrease the fills so that Σ Cut will exceed Σ Fill by the estimated requirement. This adjustment usually amounts to a lowering of all the calculated or graphically determined elevations by less than 0.1 foot. To prevent accumulative error it is advisable while making these calculations to maintain an accuracy to the second place beyond the decimal or to the nearest 0.01 foot.

To illustrate, proceed with problem presented in the diagram on page 32, as restated and further developed in the diagram on page 37. From depths of cut and fill as first obtained by subtracting the original elevation at each grid point from the corresponding calculated elevation,

$$\Sigma \text{ Cut} = 7.950 \text{ feet}$$
$$\Sigma \text{ Fill} = 7.940 \text{ feet}$$

and

$$\frac{7.950}{7.940} \times 100 = 100.1\%$$

The total cut in this case is approximately 100 per cent of the total fill instead of the 130 per cent estimated to be required, so adjustment is necessary. If all the calculated grid-corner elevations are lowered by 0.05 foot

$$\Sigma \text{ Cut} = 8.737 \text{ feet}$$
$$\Sigma \text{ Fill} = 7.227 \text{ feet}$$

and

$$\frac{8.737}{7.227} \times 100 = 121\%$$

Try a lowering of 0.07 foot, which makes

$$\Sigma \text{ Cut} = 9.092 \text{ feet}$$
$$\Sigma \text{ Fill} = 6.982 \text{ feet}$$

and

$$\frac{9.092}{6.982} \times 100 = 130.2\%$$

The cuts and fills first obtained are altered accordingly on the base map and with one exception are posted in the field without further change. The exception pertains to the depths of fill. It is known from experience with leveled land that settling occurs in the fills after the grading is completed. It is customary at the time of posting in the field to add 10 per cent to the adjusted depths of fill listed on the base map. Very likely there is considerable difference in the allowance that should be made depending upon the structure of the soil as it goes into the fill. Clean, dry sand should settle very little, while dry, cloddy clay or adobe might be expected to consolidate more than the 10 per cent. It is often the experience that some regrading must be done due to too little crowning of the fills.

Final adjustments are made after the work of grading the land has progressed far enough to show the need for it. The prescribed slope in the direction of irrigation should remain unchanged with two possible exceptions. If the volume of cut in relation to the volume of fill proves insufficient, it may be increased by flattening the slope in the first 50 feet and/or steepening it in the last 50 feet of the irrigation run. These changes may even improve the irrigation slope in some cases by providing better opportunity for the irrigation stream to spread before it starts down slope and by affording better surface drainage at the lower end of the field. Any necessary additional adjustment should be confined to alteration of the cross slope. This is accomplished by lowering or raising as need be the posted elevations at all grid corners on any line parallel to the direction of irrigation. The lines so changed should be selected to avoid excessive cross slope at any point.

III. Earthwork Calculations

The yardage of excavation, or total volume of cut, is the principal basis for estimating equipment requirements and costs. If the work is to be paid for by the cubic yard of excavation, it is reasonable to expect, unless agreement otherwise has been reached, that this yardage is accurately calculated. Other uses for the information usually require less accuracy with a corresponding saving of time or expense.

The volume of cut in a grid square which lies entirely within an area of cut is most accurately computed by the prismoidal formula, but the degree of accuracy warranted may be obtained by the less involved method of average end areas, which may be expressed as:

$$V = \frac{A(C_1 + C_2 + C_3 + C_4)}{27 \times 4} \text{ cubic yards}$$

in which V = cubic yards of cut in the grid square

A = area of the grid square in square feet

C_1, C_2, C_3, and C_4 = depths of cut in feet at the four grid corners

If the grid system is laid out as illustrated in the chart on page 10 with all four corners one-half the distance between grid corners from the boundary of the field and it is assumed that no change or break in slope occurs other than as indicated by the grid corner levels, the sum of the volumes of cut (Σ V) of all grid squares

which lie entirely within areas of cut may be accurately obtained by extending the above formula to:

$$V = \frac{\Sigma A\,[(C_1)(n_1) + (C_2)(n_2) + (C_3)(n_3) + \ldots (C_n)(n_n)]}{27 \times \Sigma n} \text{ cubic yards}$$

in which ΣA = sum of the area of all of the grid squares in square feet.

$C_1, C_2, C_3, \ldots C_n$ = the different numerical values of the depths of cut at grid corners.

$n_1, n_2, n_3, \ldots n_n$ = the total number of times each of these numerical values ($C_1, C_2, C_3, \ldots C_n$) would be used were the volumes of the grid squares calculated separately.

Σn = the sum of all the n's defined above

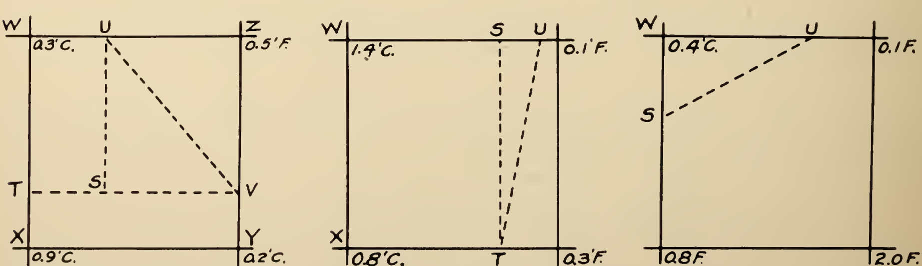
This formula reduces to the simpler form:

$$V = \frac{(\Sigma \text{ cuts at all grid corners in feet})\ (\text{Area of one grid square in sq. ft.})}{27}$$

The volume of cut in each of the remaining grid squares, or those which lie only partially in areas of cut, cannot be accurately determined in the same way, though at least a part of the error is compensating and for a whole field it may be insignificant. Such is the assumption in the procedure followed in making the cut and fill adjustment. Also the total volume of earth excavation is frequently calculated entirely in this manner for jobs which are paid for by the tractor hour in order to check the cost against the fair cost of earth excavation by the cubic yard. Furthermore, if agreed to beforehand, it can be the basis for settlement even when the work is let by the cubic yard of excavation.

If volume of cut must be calculated with greater accuracy as, perhaps, should be the case when land grading is contracted on the yardage basis, it is necessary to determine more precisely the volume of cut in those grid squares which are only partly in areas of cut. When the grid system consists of squares, these calculations can be computed fairly simply by the average end areas method when cut is called for at one, two, or three corners of a grid square and fill is required at the remaining corners.

The grid square and earth mass to be excavated is divided for this purpose into areas and volumes which can be computed separately and combined to give the total volume of cut in each grid square. Thus in the left diagram below, in which three corners are in cut and one in fill, the grid square may be divided into rectangles TSUW and XTVY and triangle SUV. These areas would then be computed as follows



Left: Division of cut area into triangles and rectangles for computing volumes of earth excavations when three corners of a grid square are in cut.
Center: When two grid corners are in cut. Right: When one grid corner is in cut.

(See Searles, W. H., Ives, H. C., and Kissam, P. *Field Engineering*. John Wiley, N.Y., 2d Ed., 1949.) :

Area of TSUW = (WU) (TW) (The distances WU and TW are obtained by interpolation as previously explained)

$$= (3/8 \times 100)\ (5/7 \times 100)$$
$$= 2679 \text{ square feet.}$$

Area of XTVY

$$= (XY)\,(VY)$$
$$= 100\ (2/7 \times 100)$$
$$= 2857 \text{ square feet.}$$

Area of SUV

$$= \tfrac{1}{2}\,(SV)\,(SU)$$
$$= \frac{(5/8 \times 100)}{2}\ (5/7 \times 100)$$
$$= 2232 \text{ square feet.}$$

The volumes of the three earth masses which have as their bases rectangles TSUW and XTVY, and triangle SUV can then be computed and combined to obtain the total volume of cut in the grid square, thus:

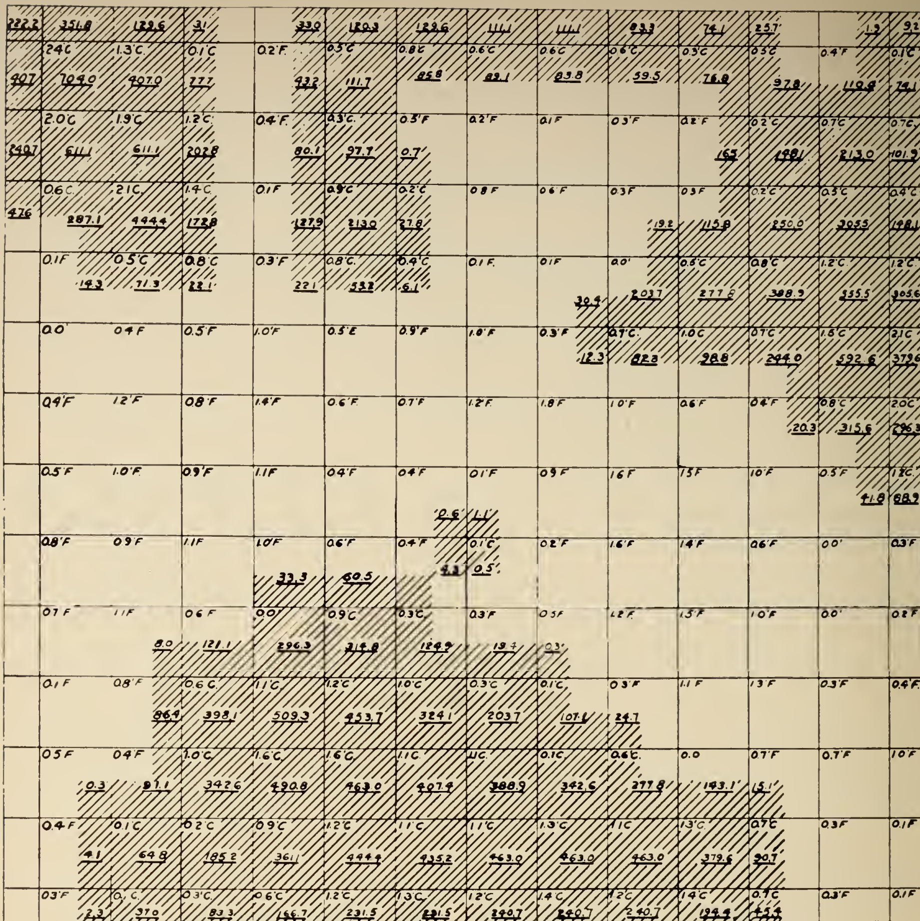
$$\text{Volume of cut in WXYVU} = \left\{ 2679\,\frac{(.3 + 0 + .456 + .729)}{4} + 2857\,\frac{(.729 + 0 + .2 + .9)}{4} + 2232\,\frac{(0 + .456 + 0)}{3} \right\} \div 27$$
$$= 97.7 \text{ cubic yards.}$$

When two of the corners are in cut and two in fill as shown in the central diagram on page 42 two areas and two volumes must be determined to obtain cubic yards of cut, thus:

$$\text{Area WSTX} = (8/11 \times 100)\ 100$$
$$= 7273 \text{ square feet.}$$
$$\text{Area TSU} = \frac{(14/15 \times 100 - 8/11 \times 100)}{2}\,100$$
$$= 1030 \text{ square feet.}$$
$$\text{Volume WSTX} = 7273\ \frac{(1.4 + 0.309 + 0 + 0.8)}{4}$$
$$= 4560 \text{ cubic feet.}$$
$$\text{Volume TSU} = \frac{(0.309 + 0 + 0)}{3}\ 1030$$
$$= 106 \text{ cubic feet.}$$
$$\text{Volume TXWU} = \frac{4560 + 106}{27} = 173 \text{ cubic yards.}$$

In the only remaining case when one isolated corner is in cut as shown in the right diagram on page 42 it is necessary to compute only one area and one volume, thus:

$$\text{Area SUW} = \frac{(4/5 \times 100)\ (4/12 \times 100)}{2}$$
$$= 1{,}333 \text{ square feet.}$$
$$\text{Volume SUW} = \frac{1{,}333\ (0.0 + 0.4 + 0.0)}{3 \times 27}$$
$$= 6.6 \text{ cubic yards.}$$



Base map of field to be graded showing the distribution of cut and the volume of cut by grid squares.

In case the grid system consists of grid blocks that are not square, it is necessary to know the interior angles of the grid blocks and to compute the fractional areas by trigonometry which makes the procedure much more involved and time consuming.

The yardage of excavation of the square grid system shown above has been computed both by the above unit volume method and formula $V = A\Sigma C/27$ in which A is the area of one grid square. As the yardages were computed by this unit volume method, each result was written within the corresponding grid square on the map. Thus by inspection it could be seen that the calculated quantities were consistent and complete.

The total quantity of earth excavation arrived at in this manner is 23,570 cubic yards, while that obtained less accurately by the formula $V = A\Sigma C/27$ is 25,555 cubic yards. Different results—some showing closer agreement and some greater disagreement—may be expected for each parcel of land considered.

IV. Haul Distance Calculations

The haul distance beyond which it is economical to switch from the slow traveling crawler tractor unit to the high speed rubber-tired wheel equipment is determined by the relative costs of moving a cubic yard of earth the different haul distances. To obtain this unit cost it is necessary to know the costs of ownership and operation and the production rates for each machine. The following items make up the ownership and operation cost.

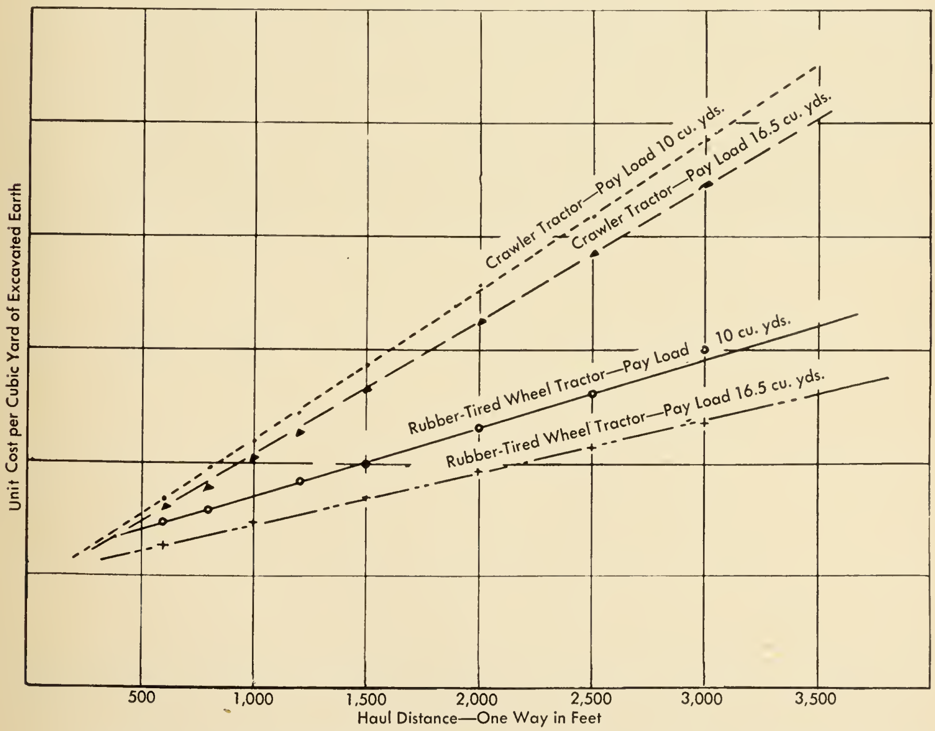
Fixed cost based on 10,000 hours operation:

- Depreciation
- Interest, insurance and taxes

Variable cost:

- Fuel
- Gasoline for cleaning and starting
- Lubricating oil and grease
- Labor for oiling and greasing
- Repairs—labor and parts
- Tires
- Operator

The production rate per hour of operation, or cubic yards of earth moved per hour is arrived at by knowing the capacity in cubic yards of each equipment unit and noting the number of loads moved per hour for each haul distance. The resulting rates apply, of course, only when the scrapers are being loaded to capacity.



Production curves for different types and size of size of earth-moving equipment.

The unit cost of earth moving for each machine, for each haul distance and for the one set of ground surface conditions may then be computed as follows:

$$\frac{\text{Fixed cost} + \text{variable cost per hour}}{\text{Cubic yards of earth moved per hour}} = \text{Cost per cubic yard of earth moved.}$$

To be always comparable this cost should be based on bank or cut measure, or

$$\frac{\text{Depth of cut in feet} \times \text{area in square feet}}{27} = \text{Cubic yards of excavation, cut measure.}$$

Carrier-type scraper capacities are usually described as the contents of the bowl when level full (struck load), or when heaped (heaped load). The comparable cut measure (pay load) for different kinds of soil is less than these capacities by approximately 20 per cent for loamy soils, 25 per cent for average soils, and 33 per cent for dense clay.

By examining the unit cost of earth moving by the different sizes and types of equipment, or by plotting them as shown in the diagram on page 45 for a fairly firm, even ground surface it can be readily seen that:

The cost per cubic yard of moving earth is lower for each larger earth mover of the same type.

There occurs a haul distance beyond which it rapidly becomes uneconomical to use crawler tractor-drawn carrier scrapers.

According to recent dealer-manufacturer information, the one-way haul distance at which properly matched and aided crawler tractor and rubber-tired wheel tractor carrier scraper units can operate at approximately the same unit cost is 500 feet. The lack of precision with which tractor-scraper units and a pusher tractor operate, when the one-way haul distance is 500 feet or less, cancels out any advantage in haul speed. Under extremely unfavorable soil conditions, this break-even point might be 800 feet or more.

Recent experiments with weighting and increasing the bearing surface of four-wheel, rubber-tired tractors to give them more effective power while loading promised to increase materially their production rates and to make them superior at all haul distances.

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and this is what it looks like . . .

THE PHOTO above is taken from a circular on irrigated pastures in California. It shows a good lay-out of fences and gates for rotation grazing.

The drawing below is from a circular on selective weed killers and shows one reason why some weed killers are selective.

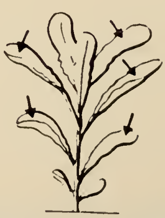
These pictures are typical of the practical, down-to-earth approach to farm problems used in many of the free publications put out by the University of California College of Agriculture.

In editing these publications, the rule is: tell it simply; if it can't be told simply, use a photograph; if a photograph won't show it, draw a picture.

The publications cover a wide variety of farm subjects, and their aim is to present useful information developed by the University's specialists, in a clear, easy-to-read manner.

Perhaps one or more of these publications will help YOU with your farm problems. For a catalog listing all of the publications available, see your County Farm Advisor or write to:

SPRAY BOUNCES OFF CEREAL LEAVES



SPRAY STICKS TO WIDER, HORIZONTAL LEAVES

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